1991

Effect of Future Sea Level Rise on Barrier Migration and Headland Erosion Along the Southern Coast of Rhode Island

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EFFECT OF FUTURE SEA LEVEL RISE ON BARRIER MIGRATION AND HEADLAND EROSION ALONG THE SOUTHERN COAST OF RHODE ISLAND

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY

UNIVERSITY OF RHODE ISLAND

1991

ABSTRACT

The southern coast of Rhode Island consists of a series of barriers and headlands currently retreating landward by inundation and frontal erosion. Over the next century, a projected atmospheric temperature increase caused by the continued emission and buildup of greenhouse gases may elevate eustatic sea level by inducing the thermal expansion of the oceans and the melting of glaciers (Hoffman and others, 1983; Meier, 1989; Houghton and others, 1990). Using the mid-moderate projection for eustatic sea level rise of the Environmental Protection Agency (EPA) (Hoffman, 1984) and the rate of local subsidence (1.5 ± 0.5 $mm \cdot yr^{-1}$), local projections of sea-level rise were determined for the years 2020, 2050 and 2100. These projections were two to four times greater than the historical sea-level rise rate extrapolated over the same time period.

To model the effect of projected sea-level change in Rhode Island, nine coastal profiles were surveyed. Landform changes were modelled using two methods, a historical erosion method (HEM) and a method adopted by National Academy of Sciences (NAS) (NAS, 1990) that incorporates historical erosion rates and projected sea-level rise rates. Frontal erosion ranged from 3 to 102 m for HEM-modelled profiles and from 5 to 363 m for NAS-modelled profiles. Both methods showed barrier profiles had greater frontal erosion than headland profiles. A sediment-budget analysis

of modelled profiles gave the ratio of eroded sediment from source areas along the profile to sediment deposited in sink areas. The NAS-modelled profiles generally exhibited a surplus of eroded source material, while the HEM-modelled profiles showed a sediment source deficit.

The effect of a 100-year storm was modelled at each site for 2020, 2050 and 2100. Berm and foredune zone erosion averaged 50 $m^3 \cdot m^{-1}$ and foredune retreat averaged 36 m. By 2100, a 100-year storm surge will flood most of the first floors of the structures surveyed.

During the next 110 years, Federal Emergency Management Agency (FEMA) V and A flood zones will migrate landward with a rising sea level. Analysis of beach profiles showed A-zones extending landward up to 342 m. The combined length of FEMA V- and A-zones along a profile, however, will change little over time as frontal erosion keeps pace with the landward extension of the A-zones.

Present coastal legislation in Rhode Island should revise structural setback distances based on erosion hazard zones, and include updated projections for future sea level elevations.

ACKNOWLEDGMENTS

I would like to thank my advisor, Jon C. Boothroyd, for teaching me geology and its many definitions, and for providing me with financial support during my graduate years.

To Dr. Robert McMaster and to Dr. David E. Fastovsky, thanks for many enlightening discussions about geology and for being on my thesis defense committee.

Allyn Foss and Joshua B. Holden deserve much more than the few lunches and beer or two they received for helping me with the field work. Thanks, gentlemen, for all of your assistance.

I wish to thank Chris Galagan for showing me around the "Environmental Geology Data Facility" and for engaging in some much needed sport talk.

To all my friends who helped through these years in the Geology Department - Jeff Campbell, Pat Craft, Tom Dunham, Carol Gibson, Scot Graves, Nasir Hami-"Quarters", Ron Harwood, Anton Maria, Nancy Nevins, Sue Ponte, Pat Pryor, Rob Shutsky, Matt Smith, Valerie (Vali) Tamm, Anne Veeger, and all the others I've missed - cheers.

Special thanks go to my pal Shilo who kept me entertained throughout my last few months of school.

This thesis is dedicated to Heidi Mindnich, whose support and encouragement never wavered.

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INTRODUCTION

Local sea level is projected to increase from 1990 levels which are 20 cm above the National Geodetic Vertical Datum (NGVD), the datum used for land surface elevations throughout the United States and based on the mean sea level as observed in 1929, to 176 cm above NGVD in 2100. These projections were modelled using eustatic sea level projections (mid-moderate scenario of Hoffman and others, 1983) and historical sea level data compiled from the Newport, RI tide gauge (Lyles and others, 1987). The projected 2100 sea level elevation is almost four times greater than the 2100 sea level elevation determined by extrapolating the historical sea-level rise rate of the last century from 1990 to 2100. Consequently, greater erosion and inundation are expected for the Block Island Sound and, south of the Narrows inlet, the Rhode Island Sound coasts of Rhode Island than has been witnessed in the recent past.

The primary objective of this study is to model landform changes caused by the projected sea-level increases for 2020, 2050 and 2100. The landform changes include modelling the location of individual coastal profiles with respect to NGVD using two different migration methods, and modelling the effects of a 100-year storm event on individual coastal profiles. In addition, changes to Federal Emergency Management Agency (FEMA) flood zones and wave envelopes are computed. All of these changes are graphically computed on computer-generated profiles for each site.

PHYSICAL SETTING

The study area is located along the southern coast of Rhode Island from Watch Hill Point eastward to Point Judith on Block Island Sound, and extends north to the Narrows in Narragansett on Rhode Island Sound (Figs. 1 and 2). This coast is a microtidal (< 2 m tidal range), wave-dominated mixed-energy coast (after Hayes, 1979; Nummedal and Fischer, 1978). The mean tidal range is 1.1 m and the mean spring tidal range is 1.3 m (NOAA, 1988). The average wave height is 0.8 m (Boothroyd and others, 1985).

The Block Island Sound coastline is a 35 km-long alternating series of headland bluffs and barrier spits. The headland bluffs are 0.8 to 2.5 km long, 1 to 25 m high, composed of either glacial fluvial sediment or glacial till, and fronted by sand or gravel beaches. The sandy barrier spits are 1.3 to 4.9 km long, 200 to 300 m wide, and have low frontal dunes with elevations generally 1 to 5 m high. Eight microtidal lagoons (locally called "salt ponds") back the barrier spits. Tidal exchange between Block Island Sound and the lagoons occurs through natural and stabilized inlets.

The 8.5 km-long Rhode Island Sound coastline is dominated by numerous bedrock outcrops and glacial till headland bluffs fronted by small boulder beaches. Two beaches composed of sand and some gravel occur at Scarborough and Narragansett. Scarborough beach is a

Figure 1. Location map of study area showing barriers, headlands and lagoons of the southern coast of Rhode Island.

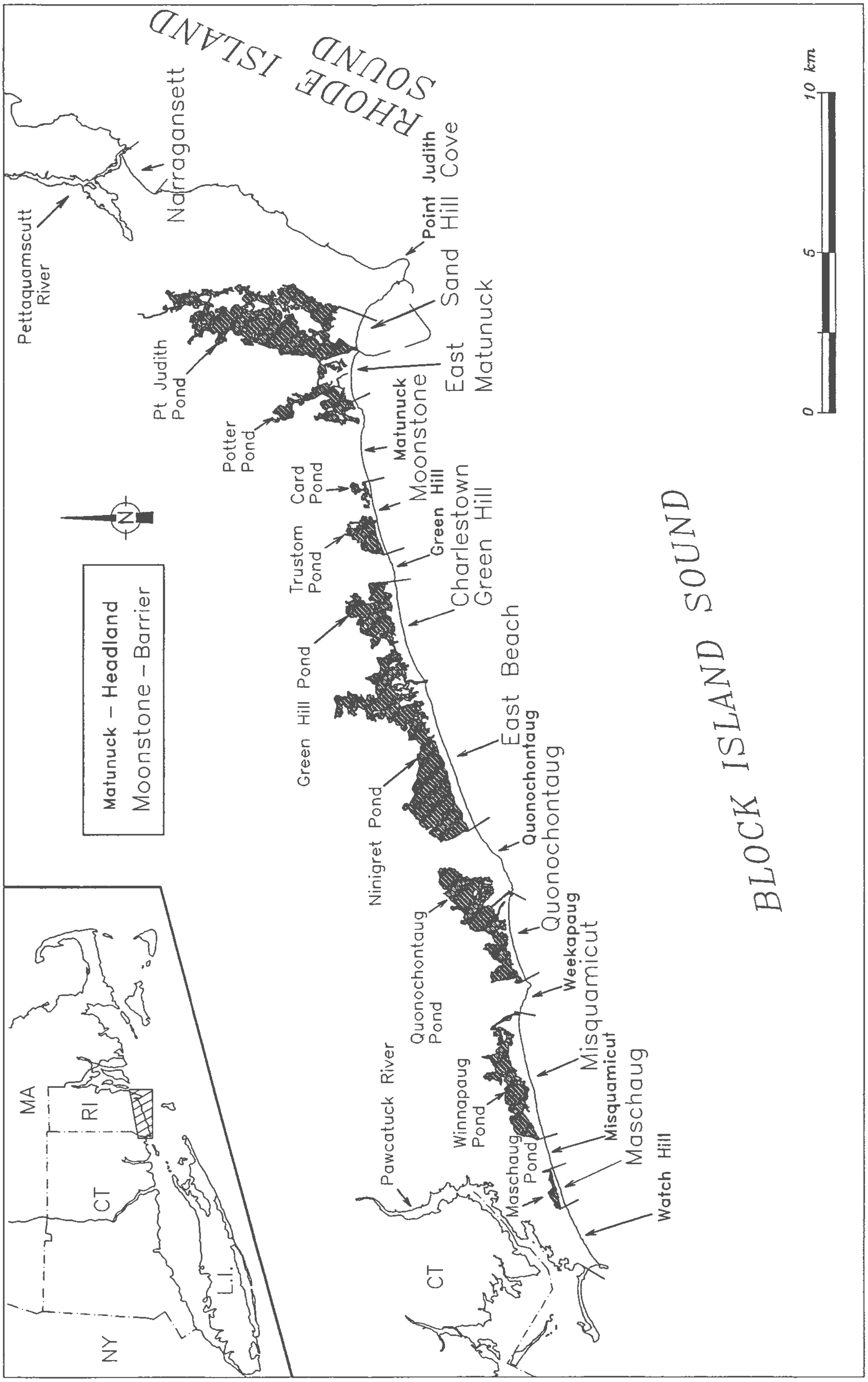
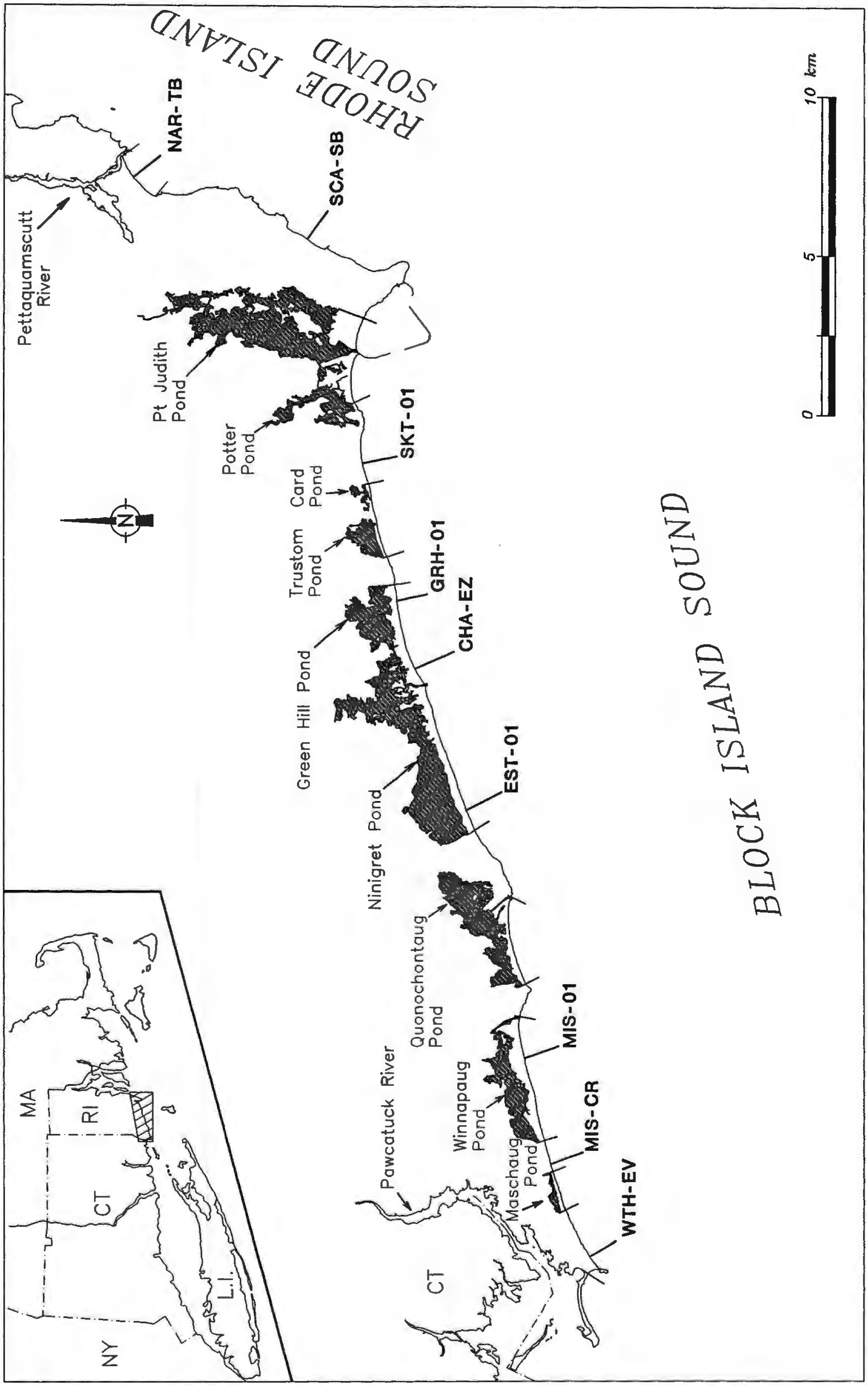

RHODE ISLAND SOUND
BLOCK ISLAND SOUND
Matunuck – Headland
Moonstone – Barrier
Pettaquamscutt River
Narragansett
Point Judith
Sand Hill Cove
Pt Judith Pond
East Matunuck
Potter Pond
Matunuck
Moonstone
Card Pond
Green Hill
Trustom Pond
Charlestown
Green Hill
Green Hill Pond
East Beach
Ninigret Pond
East Beach
Quonochontaug
Quonochontaug
Quonochontaug Pond
Weekapaug
Quonochontaug
Misquamicut
Winnapaug Pond
Misquamicut
Misquamicut
Maschaug Pond
Maschaug
Watch Hill
Pawcatuck River
CT
MA
RI
CT
NY
L.I.
N
0
5
10 km

Figure 2. Map of study area with locations of coastal profiles. Figures of the migrated coastal profiles are located in the back pocket.


RHODE ISLAND SOUND
BLOCK ISLAND SOUND
NAR-TB
SCA-SB
Pettaquamscutt River
Pt Judith Pond
Potter Pond
SKT-01
Card Pond
Trustom Pond
GRH-01
CHA-EZ
Green Hill Pond
Ninigret Pond
EST-01
Quonochontaug Pond
MIS-01
Winnapaug Pond
MIS-CR
Maschaug Pond
WTH-EV
Pawcatuck River
CT
N
0
5
10 km
MA
RI
CT
NY
L.I.

headland-fronting beach. Backing Narragansett Beach, a barrier spit, is the Pettaquamscutt River estuary which is connected to Rhode Island Sound through the Narrows inlet at the northern edge of the beach.

The Rhode Island coast is a sediment-starved, landward-migrating barrier and headland system with little upland fluvial sediment input. Sediment is supplied to the berms and low-lying backbarrier flats from Pleistocene-age glacial deposits of the shoreface and headlands, as well as from foredunes. During major winter storms and hurricanes, elevated storm surges with storm waves erode sediment from these sediment sources. The sediment is transported landward onto low-lying backbarrier flats by overwash processes and into the lagoons through tidal inlets and temporary storm-surge channels cut through the barriers. Sediment is also transported alongshore by longshore currents and offshore by rip currents.

METHODS

Coastal Profiles

Nine coastal profiles were developed along the southern Rhode Island coast. The profiles were measured using a modified Emery method (Emery, 1961; Rosenberg, 1985) and standard instrument surveying procedures. The modified Emery method measures elevation changes from a known elevation (with respect to the National Geodetic Vertical Datum of 1929) landward of the foredune crest to the plunge step, approximately mean low water (MLW). Measurements were taken perpendicular to the trend of the coastline at a maximum spacing of two meters. Specific geomorphic features and any reference markers were measured at shorter distances. Individual measurements were accurate within 5 cm horizontally and within 1 cm vertically (Boothroyd, 1987). Standard instrument surveying procedures extended the profiles landward of the known elevation to a minimum elevation of 6 m or to the seaward edge of the lagoons using a Topcon TL-20 DEP theodolite and fiberglass rod. Points were surveyed at breaks in slope, changes in vegetation and geomorphic features, roads, and to the first floor of houses. Individual measurements for this method were accurate within 50 cm horizontally and 1 cm vertically.

All profiles were continued offshore to closure depths which approximate the edge of significant sand transport under normal wave conditions. The closure depths were determined based on lower shoreface slope breaks (Dillon, 1970). Present offshore profile configurations were obtained by migrating the 1963 offshore profile configurations using historical erosion rates (from Boothroyd and others, 1988) at each site and historical sea-level rise rates multiplied by the 27-year time interval.

For barrier profiles, lagoonal depths and adjoining upland elevations were added. Lagoonal depths were determined using two methods. For the CHA-EZ and EST-01 profiles, the depths were obtained from USC&GS hydrographic charts with corrections reflecting 1990 conditions. For MIS-01 and GRH-01 profiles, depths were approximated using 1985 aerial photographs to determine the extent of the subtidal storm-surge platforms, and published literature to approximate the depths of the subtidal storm-surge platforms and of the deeper regions of the lagoons (Dacey, 1989; Boothroyd and others, 1985). The upland elevations were determined from maps using aerial photography dated 1980 (1:4,800, towns of Westerly, Charlestown and South Kingstown).

The topographic and bathymetric data of the coastal profiles were used to construct computer-generated profiles. Initially, the data were entered into a Quattro Pro™ (Borland, 1991) spreadsheet to check for field clerical errors and to produce corrected (to NGVD) x-y coordinates. The corrected data were converted to ASCII files and, using AutoLISP™ routines written by the author, read into the drawing program AutoCAD™ (Autodesk, 1990) and used to construct computer-generated profiles for 1990, 2020, 2050 and 2100. All profiles were constructed with a 10:1 vertical exaggeration.

Sea Level Rise Projections

Local sea-level rise projections were determined by adding the projected local subsidence rate to projected eustatic sea level rise rates from Hoffman (1984) and to the 1980 local sea level elevation above NGVD. Gornitz and Lebedeff (1987) have estimated the eustatic mean sea-level rise for the last century to be $1.26 \pm 0.3\ mm \cdot yr^{-1}$. Using annual mean sea-level values measured at the Newport tide gauge from 1931 through 1986, Lyles and others (1987) determined the historic rate of relative sea level rise to be $2.7 \pm 0.2\ mm \cdot yr^{-1}$ using linear regression. By subtracting the eustatic rate of sea-level rise from the local relative rate of rise, local subsidence has accounted for $1.5 \pm 0.5\ mm \cdot yr^{-1}$ of the observed changes (Fig. 3). The local subsidence rate was then multiplied by the projected number of years from 1980 and added to the projected mid-moderate eustatic sea levels of Hoffman (1984) to determine projected local levels (Fig. 4). It should be noted that, presently, there is no direct evidence for an increasing trend in the rate of sea level rise due to the greenhouse effect because the current time frame is at the inflection

Figure 3. Historic trend of annual mean sea level at Newport, Rhode Island. Historic trend was determined using linear regression analysis through annual mean sea levels from the Newport tide gauge (Lyles and others, 1987).

HISTORIC TREND OF ANNUAL MEAN SEA LEVEL NEWPORT, RHODE ISLAND

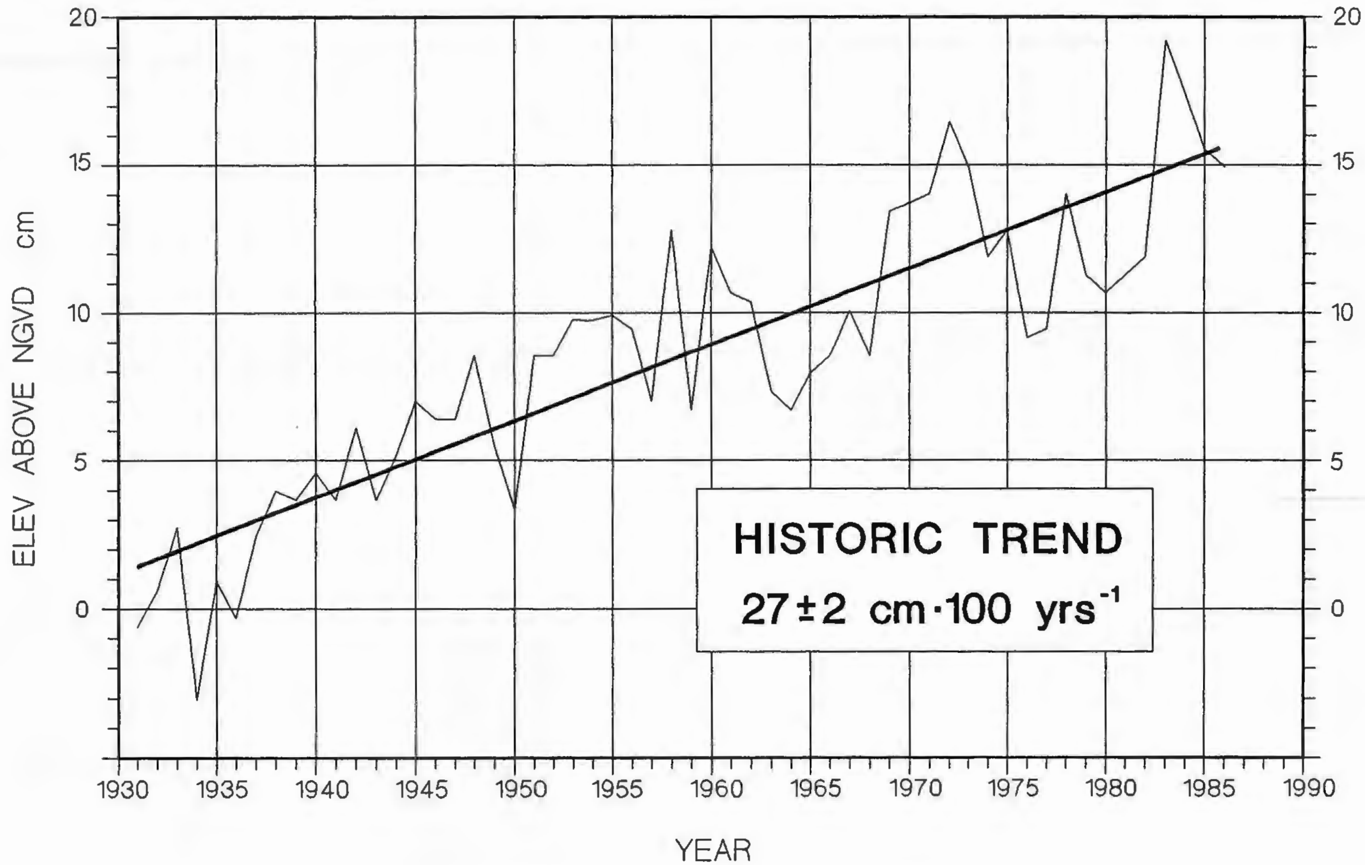
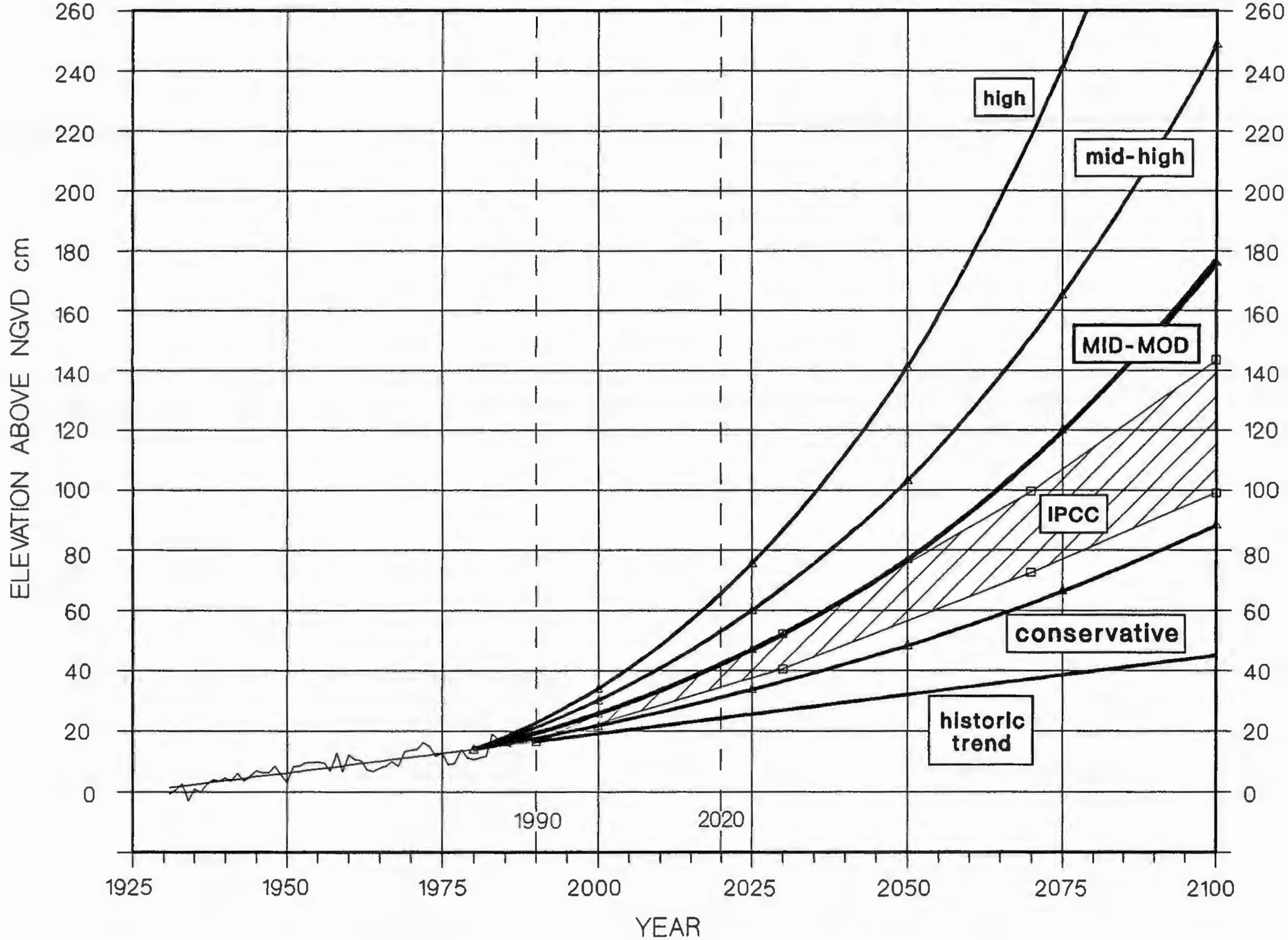


Figure 4. Projected sea level rise at Newport, RI using data from Hoffman (1984) and IPCC (Houghton and others, 1989). Projected curves also include local isostatic rebound of $1.5 \pm 0.5\ mm \cdot yr^{-1}$. The curves initiate from 1980 at 14 cm above NGVD as determined from historic levels.

PROJECTED SEA LEVEL RISE AT NEWPORT, RI

Data from Hoffman (1984) and IPCC (Houghton and others, 1990)



point where the rate changes. The 1990 projected sea level elevation at Newport is 20 cm above NGVD.

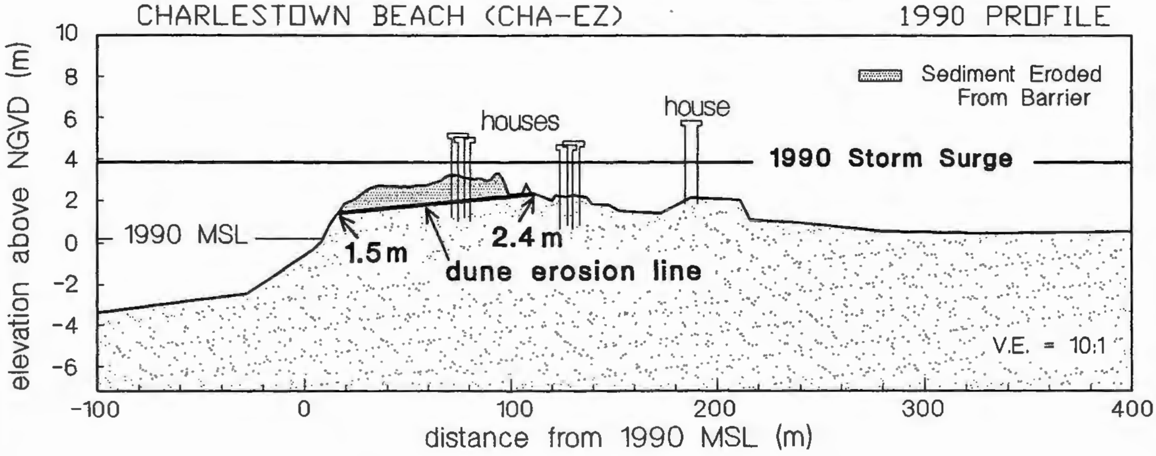
100-Year Storm Event Erosional Profile

The erosional profiles were modelled using different methods for removing material from the dunes and the beaches. The method used to model the dunes in this study was applied to the southern coast of Rhode Island by the Federal Emergency Management Agency (FEMA) during their flood insurance studies (FEMA, 1986a, b, c, and d). Eroded dunes were modelled by locating the intersection of the foredune at an elevation of 1.5 m (5 ft) and extending a line landward through the dunes to an intersecting elevation of 2.4 m (8 ft) (Fig. 5a). Based on observations of local coastal processes during storm events and on beach monitoring studies (Boothroyd and others, 1978; Boothroyd and others, 1981), beach erosion was modelled beginning at a position 20 m landward of the shoreline. From this position, a line with a slope equivalent to the slope of the foredune ramp was extended upward until it intersected the dune. Another line was extended seaward of the 20 m position to a point approximately 1 m below mean low water (Fig. 5b). This eroded beach configuration was combined with the eroded dune configuration to produce an erosional profile (Fig. 5c). No attempt was made to model depositional changes offshore, on the backbarrier flats, or

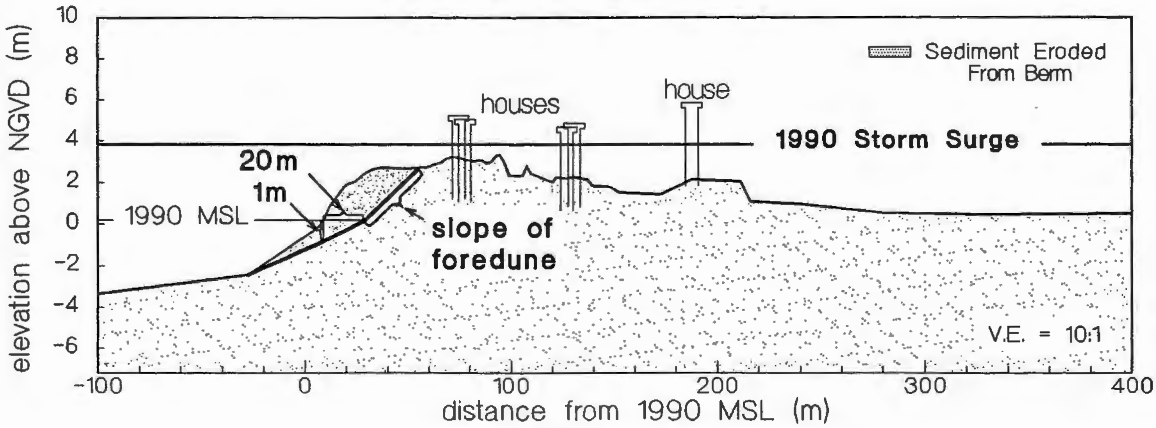
Figure 5. Profile from Charlestown (CHA-EZ) illustrating methods for determining the erosional profile caused by an 100-year storm event. A) Dune erosion is modelled by drawing a line through the foredune zone at an elevation of 1.5 m on the seaward side to an elevation of 2.4 m on the landward side (after FEMA, 1986a-d). B) The no-berm condition is modelled beginning at a distance 20 m landward of MSL. At this point, a line is extended seaward, passing 1 m below the position of MSL, until it intersects the profile. C) The erosional profile, in bold, comprises the modelled dune and beach erosion profiles.

100-YEAR STORM EROSION METHODS

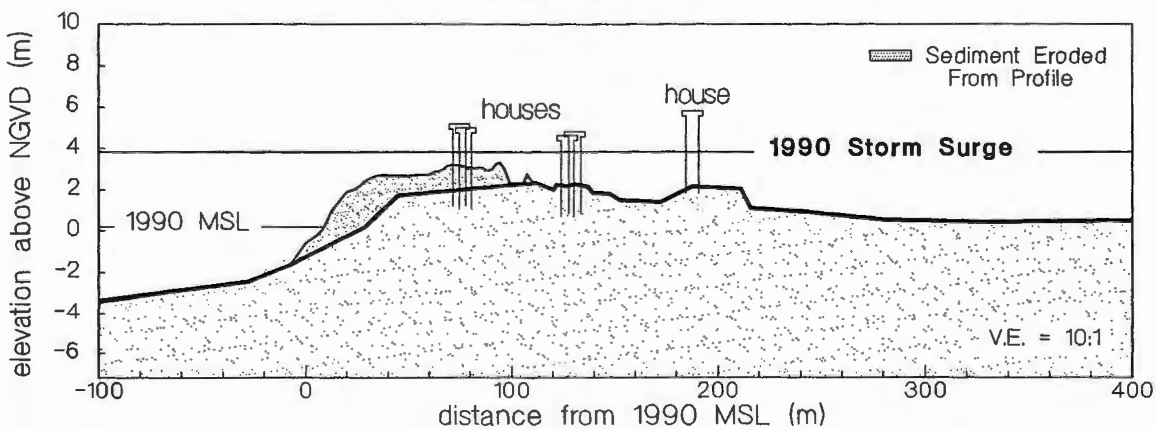
FEMA BARRIER EROSION (FEMA, 1986a-d)



NO-BERM CONDITION



100-YEAR STORM PROFILE



in the lagoons because of the lack of information regarding sediment distributions in these areas.

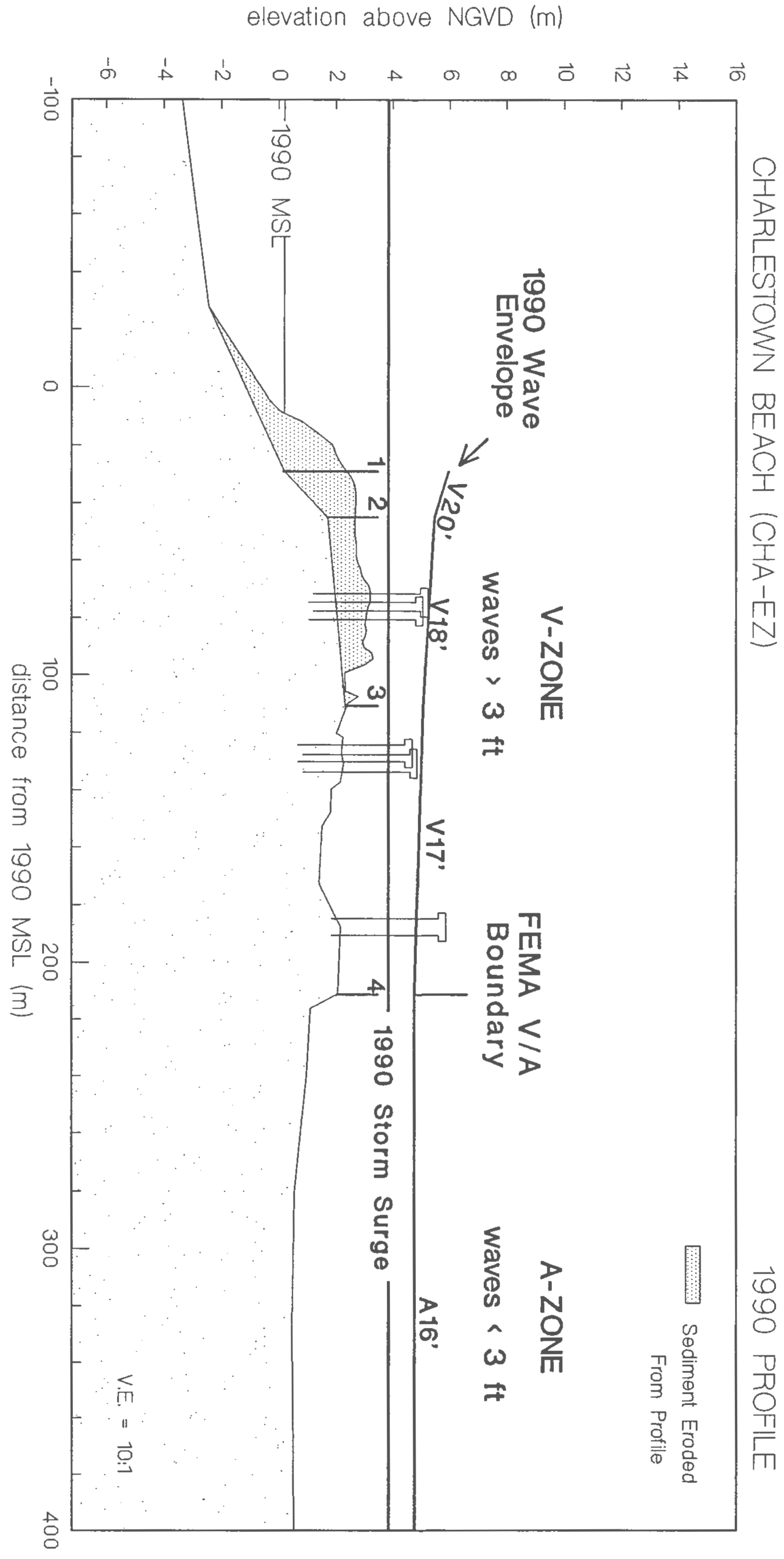
Wave Envelopes

During storm events, coastal areas are inundated by storm-surges topped with waves. To determine the areal extent and height of inundation, wave envelopes were constructed by combining storm-surge elevations with model-generated wave heights (Fig. 6).

In Rhode Island, storm-stillwater elevations have been determined by fitting a Pearson type 3 curve through flood elevations recorded after major storms as well as through 56 years of annual peak-tide levels recorded at Newport, R.I., Providence, R.I., and New London, CT. (Corps of Engineers, 1988). Elevations of the 100-year storm event range from 3.3 m at Watch Hill to 3.6 m at Charlestown to 4.2 m at Narragansett Pier.

Beginning at mean sea level at the coastline and proceeding landward, wave heights were calculated at any natural or man-made obstructions and transmitted landward until the next obstruction was encountered. Wave heights were also calculated over unimpeded fetch zones. These calculations continued until the waves intersected the upland. Runup calculations were not included in this study because of the complexity of the equations. This omission reduces the area of inundation by elevated storm surge and of breaking waves.

Figure 6. Profile from Charlestown (CHA-EZ) showing wave envelope with FEMA flood elevations and FEMA V/A boundary. Points 1 through 4 are the positions where wave-height analysis was performed.



CHARLESTOWN BEACH (CHA-EZ)
1990 PROFILE
elevation above NGVD (m)
distance from 1990 MSL (m)
1990 MSL
1990 Wave Envelope
V20'
V18'
V17'
A16'
V-ZONE
waves > 3 ft
A-ZONE
waves < 3 ft
FEMA V/A Boundary
1990 Storm Surge
Sediment Eroded From Profile
V.E. = 10:1

The water-surface elevation for each calculation was determined using the equation:

$$Z_w = S_* + 0.7H_b \qquad (1)$$

where Z_w is the water-surface elevation, S_* is the still-water depth and H_b is the crest to trough height of the maximum or breaking wave. The maximum breaking wave height at mean sea level of the coastline for a 100-year event storm-surge was determined using the equation:

$$H_b = 0.78d \qquad (2)$$

where d is the still-water depth. To determine the wave heights transmitted past obstructions, the following equation was used:

$$H_t = BH_i \qquad (3)$$

where H_t is the transmitted wave height, H_i is the incident wave height, and B is a transmission coefficient ranging from 0.0 to 1.0. Wave regeneration over unimpeded fetch zones was calculated using the equation:

$$H_f = G_* d_f \qquad (4)$$

where H_f is the regenerated wave height, G_* is an inland fetch factor related to the fetch length, and d_f is the mean depth over the fetch length. H_t and H_f of equations 3 and 4 were substituted for H_b in equation 1. More detailed discussions of the methods described above may be found in FEMA (1981) and in National Academy of Sciences (1977).

Flood Zones

Designation of FEMA V-zones and A-zones along the nine coastal profiles studied were determined from wave heights by analyzing the wave envelope at each site. V-zones are areas inundated by a 100-year storm surge plus a minimum three-foot wave. A-zones are inundated areas with waves less than three feet high (FEMA, 1986a-d). V-zones are considered high hazard zones because a minimum three-foot wave is expected to do damage to a brick or wood-frame structure. The FEMA V/A boundary for the profiles was determined by subtracting the storm-surge elevation from a wave envelope to obtain wave heights, and then locating the position of a three foot wave (Fig. 6).

Barrier Migration and Headland Retreat

After the 1990 profile configuration for each site was established, historical erosion rates (Boothroyd and others, 1988; Dein, 1981) and projected local sea levels (Fig. 4) were used to construct profile configurations for 2020, 2050 and 2100. Each site was analyzed for potential migration by computing the maximum water elevation (highest spring tide plus the sea-level surface plus the storm-surge elevation of an 100-year flooding event plus the modelled storm wave height) and comparing that value to the height of the dunes or bluff. If the height of the maximum water elevation was higher than the dunes/bluff, then the profile was presumed to have migrated. In this study, all the profiles migrated.

Profile migration can be broken down into two components: vertical and horizontal migration. The vertical migration is the projected increase in sea level from 1990 to time period t. The horizontal migration is determined using two methods for comparison, the historical erosion method (HEM) as defined in this study and the National Academy of Sciences (NAS) method (1990). The HEM models horizontal migration by multiplying the site-specific historical erosion rate by the number of years from 1990. This is expressed as follows:

$$P_t = e * t \tag{5}$$

where t is the time in years, P_t is the shoreline position at time t, and e is the historical erosion rate. This is a conservative estimate of the amount of retreat and assumes that the rate of migration will not vary from the long-term average rate of movement. The NAS (1990) method determines shoreline response based on the historical erosion trend with respect to the local sea level changes during that time interval. This approach assumes that shoreline response is directly related to changes in sea level. Therefore, if the rate of sea level rises threefold, then the rate of erosion will triple also (Leatherman, 1983). Future shoreline positions are obtained using the following expression:

$$P_t = e\ (L_{pt} / L_{ht}) * t \tag{6}$$

where L_{pt} is the projected sea level for time t, and L_{ht} is the historical rate of sea level rise multiplied by time t.

This method leads to a much greater horizontal movement for the same time interval versus the historical erosion method.

It was assumed that sediment type did not vary during migration for either the HEM or NAS method. However, one exception did occur at Watch Hill (WTH-EV). Historical erosion rates at this site have been determined from an eroding, sandy berm. A landward retreating WTH-EV NAS 2100 profile, however, would encounter the Charlestown Moraine which is composed of a sandy till with greater quantities of coarse material than the berm. The change in sediment type should result in a change in the erosion rate. The amount of erosion rate change is not calculable but is assumed to slow down. Consequently, the profile was not modelled using the NAS method. Instead, the profile was moved upward along the slope of the end moraine to an elevation equivalent to the projected 2100 sea level.

Once the projected erosion rates were determined, the 1990 profiles were modified within the Quattro Pro™ spreadsheet databases by moving the entire profile, except for houses and paved roads, landward and upward from the shoreline position. At Scarborough (SCA-SB), only the profile seaward of the seawall was modelled because it was assumed that with rising sea levels the seawall would be maintained. The Quattro Pro™ databases were then converted to ASCII files and used to construct modelled profiles in AutoCAD™.

Modifications to the modelled profiles included smoothing irregular configurations caused by overlaying migrated profiles with 30- to 110-year time intervals (Fig. 7a). Also, offshore profile configurations with elevations higher than preceding configurations were lowered to the preceding configuration (Fig. 7b). This was done because, over the long-term, the Rhode Island shoreface is erosional during sea transgressions (Dillon, 1970).

The method used in this study for modelling offshore profile configurations differs from the more widely used equilibrium profile method of Bruun (1954, 1962). The Bruun method produces the same profile configuration for a modelled profile as before, but relative to the rise in sea level (Fig. 8). This requires deposition of sediment onto the shoreface from sediment sources that include the upper shoreface, berm and foredune zone. In Rhode Island, Fisher (1980) showed from field evidence that sediment does not move exclusively offshore as the Bruun method predicts. Fisher noted that approximately 76% of eroded material could be accounted for by moving landward into flood-tidal deltas, tidal inlets and surge platforms. This leaves only 24% of the eroded material to be deposited offshore. Eventually this material also should move landward, unless offshore-flowing bottom currents move the material out beyond the closure depth onto the shelf.

Figure 7. Profile from Misquamicut (MIS-CR) depicting modifications to a migrated profile. A) Uncorrected 2100 profile is shown in bold with points 1 through 3 marking areas to be modified. The area seaward of point 1 and the area between points 1 and 2 will reflect the 1990 shoreface configuration because the Rhode Island shoreface is erosional (Dillon, 1970), not depositional as projected here. At point 3, the slope of the back of the dune will be extended down to intersect the 1990 profile because only the beach and dunes of this headland profile are migrated landward. B) Corrected 2100 profile is shown in bold.

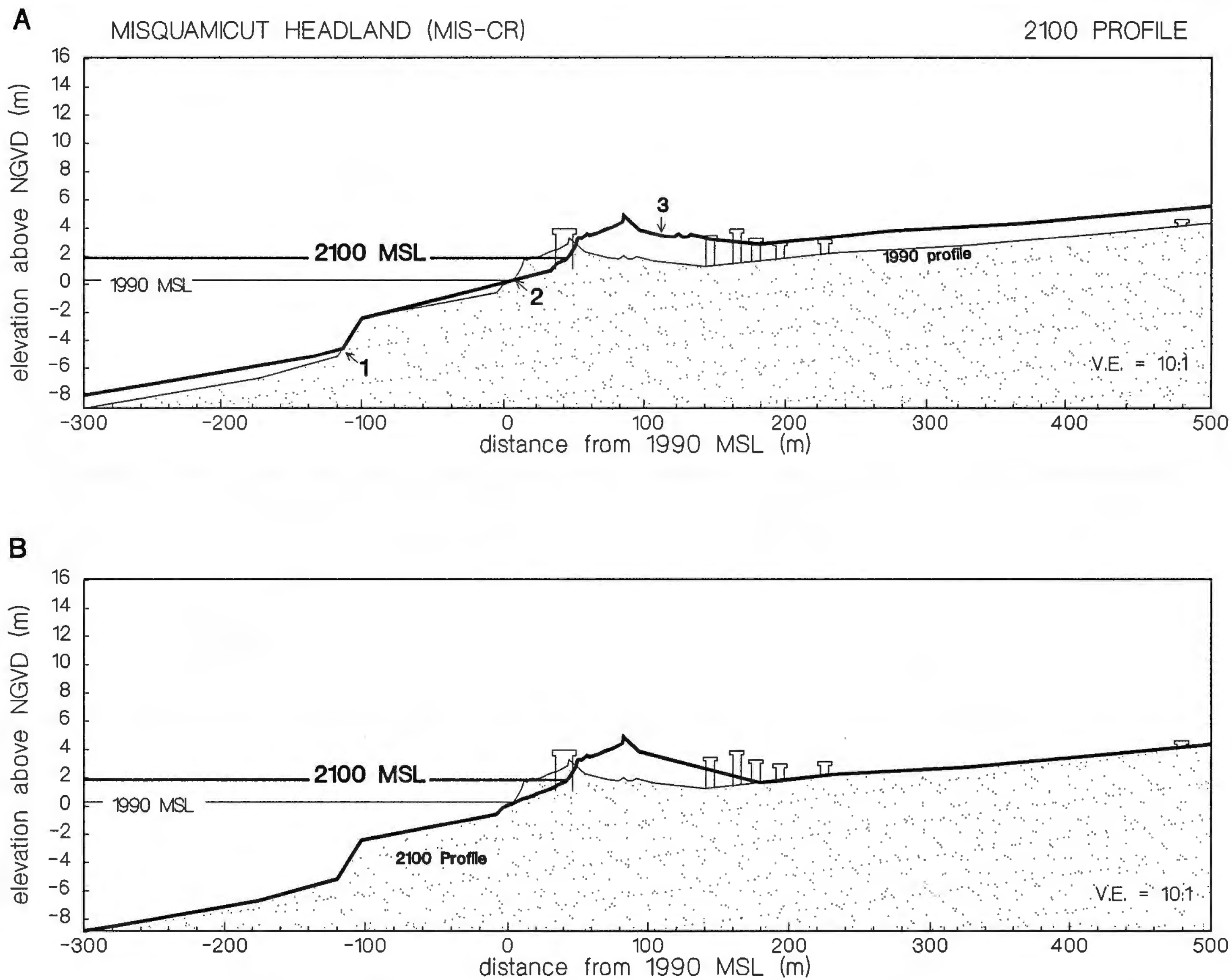
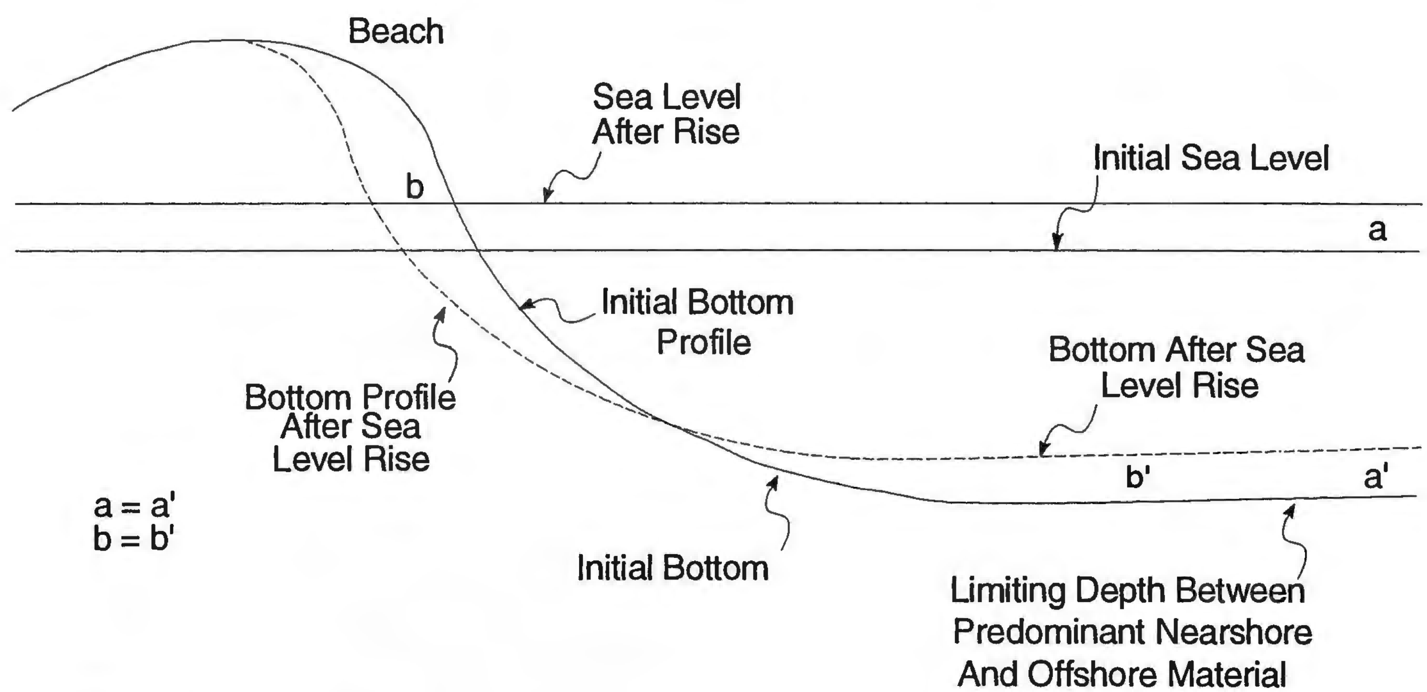

A
MISQUAMICUT HEADLAND (MIS-CR)
2100 PROFILE
elevation above NGVD (m)
2100 MSL
1990 MSL
1990 profile
1
2
3
V.E. = 10:1
distance from 1990 MSL (m)
B
elevation above NGVD (m)
2100 MSL
1990 MSL
2100 Profile
V.E. = 10:1
distance from 1990 MSL (m)

Figure 8. Shoreline erosion caused by rising sea levels using the Bruun method (Bruun, 1962). Assuming an equilibrium profile, a sea level rise equal to a will result in the nearshore bottom rising an equal amount; and, the amount of material eroded from the berm and upper shoreface will equal the amount deposited on the nearshore bottom.

Bruun Method Of Shoreline Erosion With Rising Sea Levels



(after Schwartz, 1967)

Sediment Budget Analysis

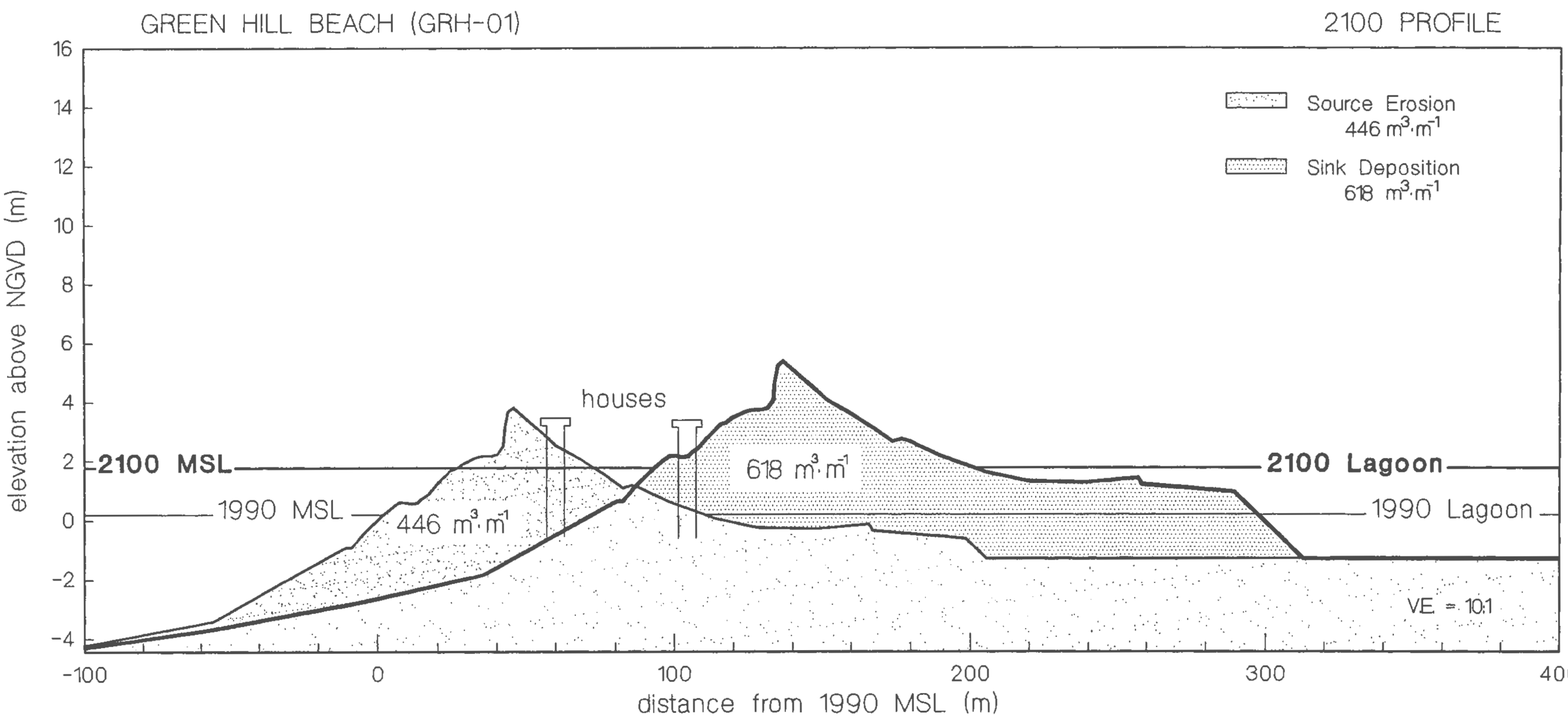
The feasibility of each migration with respect to the mass balance of sediment was determined for each profile. As each profile migrates over time, material is generally eroded from sources seaward of the dunes and deposited in sediment sinks landward of the dunes. Areas of erosion include the shoreface, berm and, sometimes, foredunes, and are depicted on the computer-generated profiles as closed polygons defined by the 1990 profile as the upper boundary and the migrated profile as the lower boundary. Depositional areas include foredunes, backbarrier flats, lagoons, marshes, and outwash plains. These areas on the computer-generated profiles are closed polygons defined by the 1990 profile as the lower boundary and the migrated profile as the upper boundary (Fig. 9). The amount of eroded and deposited sediment was obtained using the AutoCAD™ area command which calculates the area of closed polygons by triangulation.

Erosion Hazard Zones

In 1990 the National Research Council (NRC) recommended to FEMA and to FEMA's Federal Insurance Administration (FEMA/FIA) an Erosion Hazard Reduction policy, which included the identification of erosion hazard zones (E-zones), to be implemented with present National Flood Insurance Program (NFIP) guidelines. Three types of E-zones were proposed to include areas subject to imminent erosion

Figure 9. Profile from Green Hill (GRH-01) showing areas of erosion and deposition after 110 years of migration.

SOURCE EROSION AND SINK DEPOSITION



hazards (within 10 years, E-10 zone), intermediate hazards (within 30 years, E-30 zones), and long-term hazards (within 60 years, E-60 zone) (NAS, 1990). In this study, E-zones were determined for time spans of 30 and 60 years from the present with frontal erosions being calculated using both the HEM and NAS methods. The reference point where E-zones commenced were the top of foredunes or at an eroding scarp.

RESULTS

Nine sets of profiles depicting migration and the effects of an 100-year storm for the mid-moderate sea level rise scenario (Hoffman and others, 1983) for the years 2020, 2050 and 2100 were prepared from field surveys and methods already outlined. Each individual site is divided into two parts corresponding to the migration method used. Within each part, one profile shows the results of migration changes for every time interval, three profiles show enlargements of individual migrations, and three more profiles show enlargements of individual migrations with modelled 100-year storm erosions and wave envelopes. These sets of profiles are located in the back pocket. In addition, profiles depicting erosional zones (E-zones) for 30 and 60 years from the present are included. However, a thorough discussion of these E-zone profiles is beyond the scope of this study.

Shoreline displacements, as determined using the HEM and NAS migration methods, and area measurements of erosion and deposition associated with migrated profiles are found in Table 1. The area measurements of erosion and deposition quantify the sediment sources and sinks for each modelled migration along a profile. Note that the amount of material eroded does not have to equal the amount of material deposited. Deposited material may be derived elsewhere while eroded material may be transported alongshore to other

TABLE 1. Results of Migration Changes

PROFILE SITE	YEAR	FRONTAL EROSION (m) HEM	FRONTAL EROSION (m) NAS	SOURCE EROSION ($m^3 \cdot m^{-1}$) HEM	SOURCE EROSION ($m^3 \cdot m^{-1}$) NAS	SINK DEPOSITION ($m^3 \cdot m^{-1}$) HEM	SINK DEPOSITION ($m^3 \cdot m^{-1}$) NAS	% OF SOURCE EROSION TO SINK DEPOSITION HEM	% OF SOURCE EROSION TO SINK DEPOSITION NAS
	2020	20	32	154	480	35	44	440	1091
WTH-EV	2050	40	82	357	1181	61	30	585	3937
	2100	73	109	432	1194	116	45	372	2653
	2020	3	5	7	15	15	15	47	100
MIS-CR	2050	6	13	10	37	42	46	24	80
	2100	11	39	10	108	169	192	6	56
	2020	11	17	39	78	20	25	195	312
MIS-CR*	2050	22	46	83	293	57	84	146	349
	2100	40	141	118	954	194	171	61	558
	2020	4	6	10	20	181	185	6	11
MIS-01	2050	8	16	14	48	423	462	3	10
	2100	14	51	15	94	1098	1260	1	7
	2020	10	17	53	115	209	244	25	47
MIS-01*	2050	21	44	79	260	485	581	16	45
	2100	38	137	85	674	1210	1542	7	44
	2020	14	22	77	162	185	218	42	74
EST-01	2050	27	57	118	389	417	541	28	72
	2100	50	175	142	1033	1035	1497	14	69
	2020	28	45	182	382	353	405	51	94
CHA-EZ	2050	56	118	325	1012	803	1050	41	96
	2100	102	363	483	2657	2123	2707	23	98
	2020	25	40	228	418	144	198	158	211
GRH-01	2050	50	106	369	991	295	429	125	231
	2100	91	324	446	2236	618	802	72	279
	2020	10	15	60	120	11	12	545	1000
SKT-TB	2050	19	41	104	306	15	6	693	5100
	2100	35	125	143	959	55	44	261	220
	2020	9	18	31	173	4	2	775	865
SCA-SB	2050	18	49	39	481	9	0	433	---
	2100	31	139	39	1471	17	0	229	---
	2020	15	24	46	138	38	48	122	286
NAR-TB	2050	30	64	65	359	82	111	80	323
	2100	55	195	54	1098	265	194	20	565

* Adjusted erosion rates. See text.

TABLE 2. V/A-Zone Changes Over 110 Years

PROFILE SITE	1990 V/A-ZONE LENGTH (m)	YEAR	A-ZONE EXTENSION (m) HEM	A-ZONE EXTENSION (m) NAS	FRONTAL EROSION (m) HEM	FRONTAL EROSION (m) NAS	% OF 1990 V/A-ZONE LENGTH HEM	% OF 1990 V/A-ZONE LENGTH NAS
		2020	10	10	20	32	96	90
WTH-EV	225	2050	26	26	40	82	94	75
		2100	74	74	73	109	100	84
		2020	21	21	3	5	102	102
MIS-CR	767	2050	50	50	6	10	106	105
		2100	146	146	11	39	118	114
		2020	21	21	11	17	101	100
MIS-CR*	767	2050	50	50	22	35	104	102
		2100	146	146	39	141	114	101
		2020	2	2	4	6	100	100
MIS-01	1621	2050	5	5	8	17	100	99
		2100	51	51	14	51	102	100
		2020	2	2	11	17	99	99
MIS-01*	1621	2050	5	5	22	45	99	98
		2100	51	51	39	137	101	95
		2020	9	9	14	22	100	99
EST-01	2428	2050	23	23	27	57	99	98
		2100	66	66	50	175	100	95
		2020	11	11	28	45	99	98
CHA-EZ	1838	2050	29	29	56	118	99	95
		2100	82	82	102	363	99	85
		2020	18	18	25	40	100	99
GRH-01	1845	2050	58	58	50	106	100	97
		2100	342	342	91	324	114	101
		2020	10	15	10	15	100	100
SKT-TB	11	2050	19	41	19	41	100	100
		2100	35	125	55	125	100	100
		2020	4	4	9	18	97	92
SCA-SB	173	2050	9	9	18	49	95	77
		2100	34	34	31	139	101	39
		2020	3	3	15	24	97	95
NAR-TB	373	2050	7	7	30	64	94	87
		2100	20	20	55	195	92	69

* Adjusted erosion rates. See text.

profiles. Table 2 outlines the landward extension of FEMA A-zones and the percentage of change in total length of FEMA V/A-zones for each migrated profile.

Watch Hill Headland Profile (WTH-EV)

The Watch Hill profile is located on Everett Avenue approximately 1.0 km east of the Watch Hill Light House (Figs. 10, 11 and 32). This headland profile begins at mean low water (MLW), passes along a beach accessway in the dunes and ends on the steeply dipping south face of the Charlestown Moraine. The few houses situated along this profile are located on the moraine.

The historical frontal erosion rate ($-0.66\ m \cdot yr^{-1}$) for this site is extremely high when compared with other headlands of the south shore (Boothroyd and others, 1988). With a 22 cm rise in sea level from present, the thirty-year HEM and NAS modelled migrations will result in the shoreline being displaced landward by 20 and 32 m, respectively. Storm surges from an 100-year storm event at this time will result in the A-zone extending landward by 10 m.

By 2050, the shoreline will retreat 40 and 82 m using HEM and NAS methods, respectively. The landward migration of depositional environments will place either the foredune

Figure 10. Location of Watch Hill (WTH-EV) profile on Everett Street in Westerly. This headland profile ends on the Charlestown End Moraine.

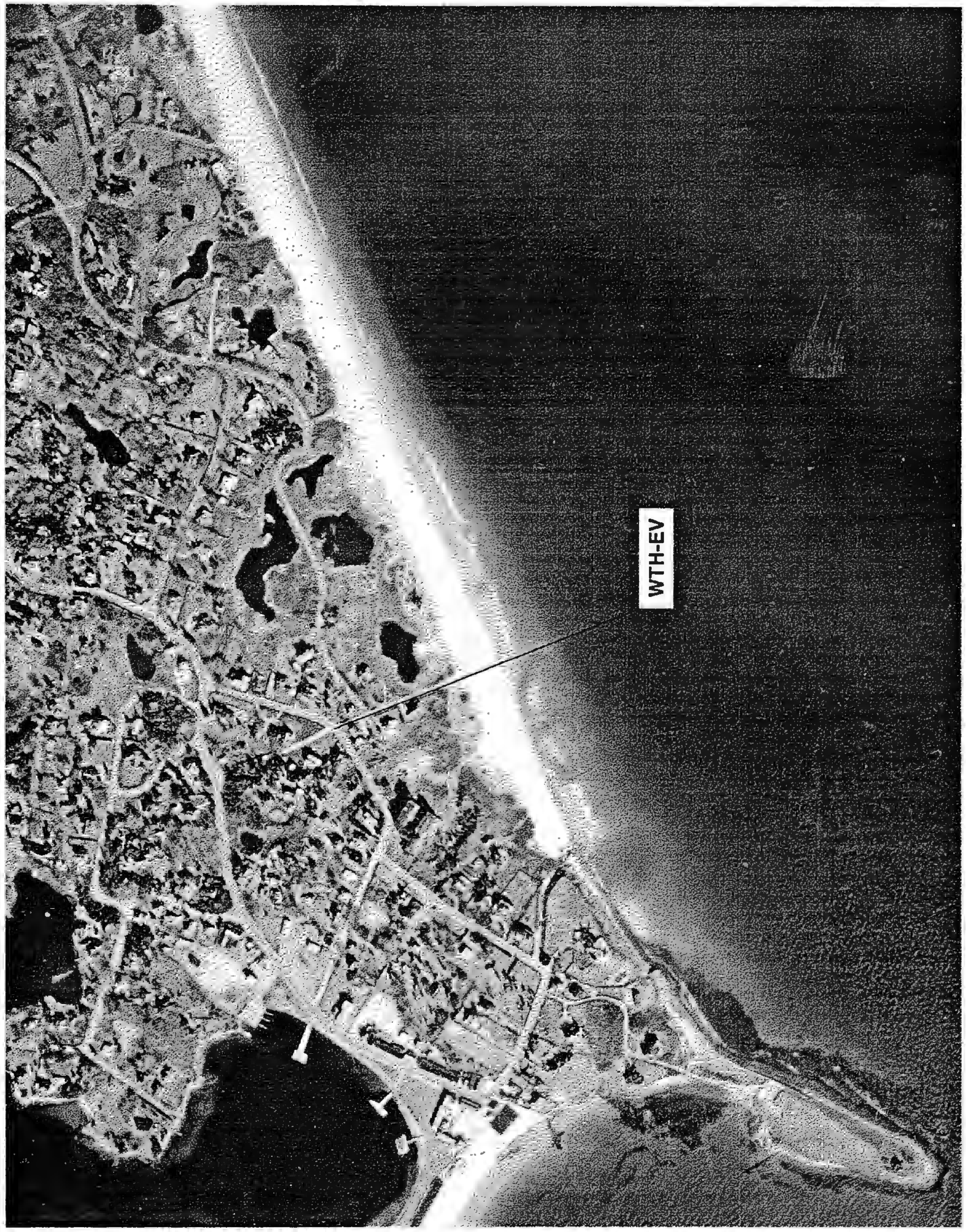
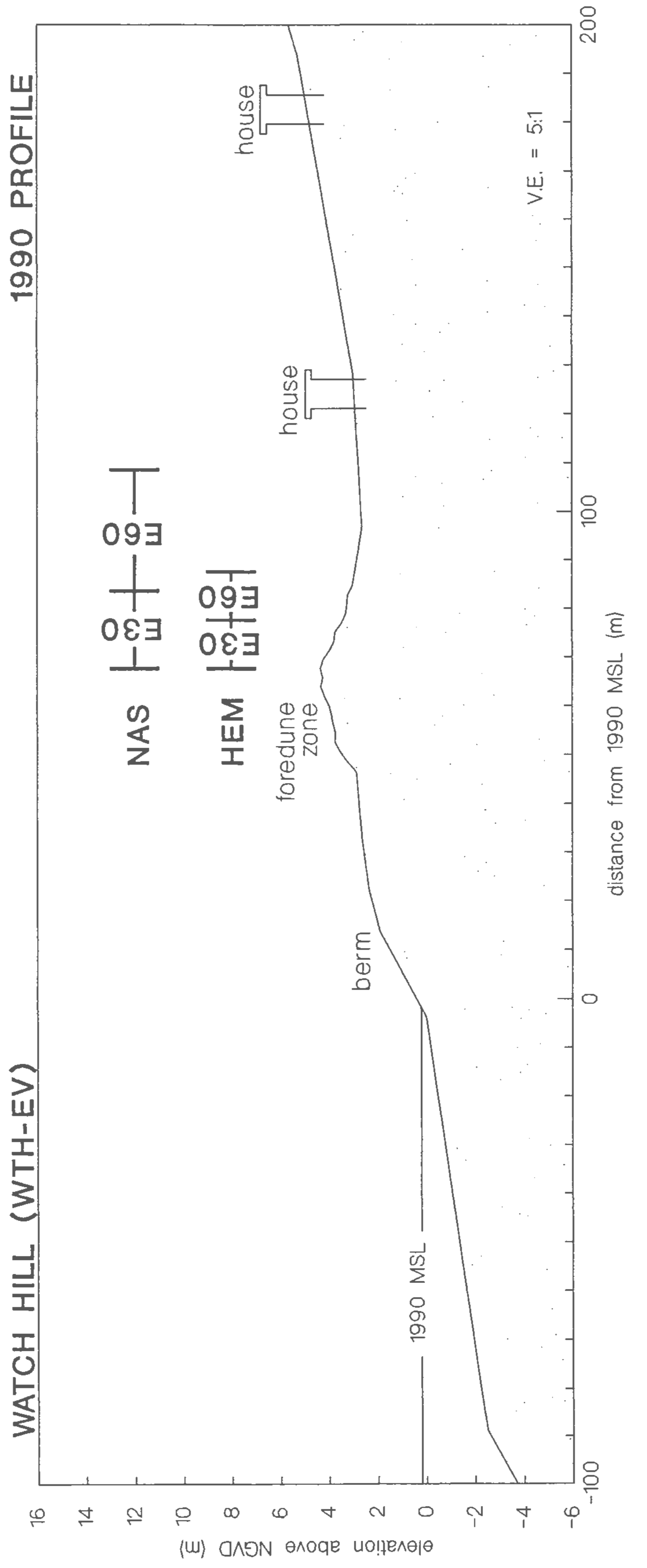

WTH-EV

Figure 11. Profile from Watch Hill (WTH-EV) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. The E-30 zone calculated using the historical erosion method (HEM) measured 20 m. Using the NAS method, the E-30 zone measured 32 m. The E-60 zone measured 40 and 82 m when calculated with the HEM and NAS methods, respectively.


WATCH HILL (WTH-EV)
1990 PROFILE
elevation above NGVD (m)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-100
0
100
200
distance from 1990 MSL (m)
1990 MSL
berm
foredune
zone
NAS
HEM
E30
E60
E30
E60
house
house
V.E. = 5:1

zone or the berm beneath the house at the base of the moraine. A 100-year storm surge on top of an expected 57 cm sea level rise will inundate 26 m of the present upland surface.

A 1.56 m rise in sea level combined with a 100-year storm surge will inundate the first-floor of the house at the base of the moraine by 2100. Headland erosion at this time will be 73 m using the HEM method and 109 m for the NAS method. The latter value is not the value projected using the NAS method; rather, it reflects a change in the migration rate due to a change in sediment type as the profile migrates across the sandy berm and foredune zone to the Charlestown Moraine.

A sediment budget analysis revealed that sediment removed from the shoreface, berm and foredune zone exceeded the amount of material required to produce the modelled configurations at this site. Using the HEM method, there was 5 to 7 times more source material removed from the modelled profiles than deposited in the sediment sinks. For the NAS method, 13 to 52 times more source material was removed. The excess source material from both methods is expected to travel east to the two Misquamicut profiles based on the longshore current direction.

Misquamicut Headland (Crandall Ave.) Profile (MIS-CR)

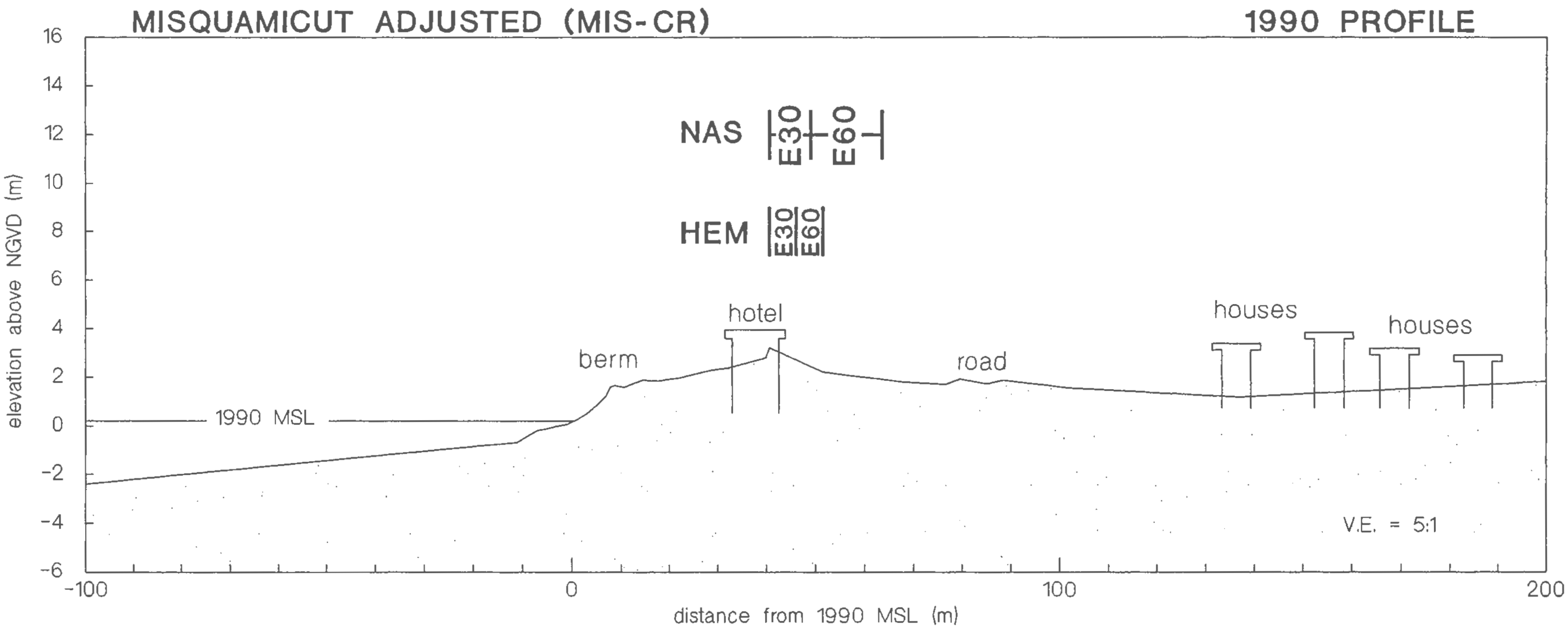
Located west of Misquamicut State Beach on Crandall Avenue, this headland profile traverses across a sand dike built on top of a gravelly storm berm and proceeds landward across a low glacial fluvial plain for 0.7 km (Figs. 12, 13 and 33). Houses line both sides of this profile and two hotels are situated directly behind the sand dike. The historical erosion rate for this section of the south shore was very low compared to adjacent transects. The historical erosion rates from adjacent transects ranged from -0.26 $m \cdot yr^{-1}$ to -0.3 $m \cdot yr^{-1}$ to the west and from -0.4 $m \cdot yr^{-1}$ to -0.6 $m \cdot yr^{-1}$ to the east compared to -0.1 $m \cdot yr^{-1}$ for this site (Boothroyd and others, 1988). The low historical erosion rate was attributed to moving sediment from surge platforms back to the area of the sand dike to protect structures on the low-lying glacial fluvial plain (Anthony Chiaradio, Director of Public Works for Town of Westerly, pers. comm., September, 1991). Therefore, two sets of profiles were prepared for this site. The first set uses the historical erosion rate from Boothroyd and others (1988). The second set uses an historical erosion rate determined by averaging adjacent transects. The erosion rates for the adjacent transects are approximately three times greater and are considered to be more representative of the natural system for this area.

Using the lower historical erosion rate, only 3 to 5 m of frontal erosion is expected for 2020. The adjusted frontal erosion rate will result in 11 to 17 m of shoreline retreat. Modelled storm surges from a 100-year event will flood many first floors of houses along this profile and

Figure 12. Location of Misquamicut (MIS-CR) profile on Crandall Avenue in Westerly. This headland profile traverses a densely populated, low-lying, glacio-fluvial plain.


MIS-CR

Figure 13. Profile from Misquamicut (MIS-CR) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. All calculations were made using the adjusted historical erosion rate as described in the text. The E-30 zone measured 11 and 17 m when calculated using the HEM and NAS migration methods, respectively. The E-60 zone measured 22 and 46 m.


MISQUAMICUT ADJUSTED (MIS-CR)
1990 PROFILE
NAS E30 E60
HEM E30 E60
hotel
houses
houses
berm
road
1990 MSL
V.E. = 5:1
elevation above NGVD (m)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-100
0
100
200
distance from 1990 MSL (m)

extend landward the upland shoreline of the A-zone by 21 m with a 22 cm rise in sea level. The length of the V/A-zones from the profile modelled using the adjusted historical erosion rate will be slightly less than for the non-adjusted rate because of the greater amount of frontal erosion (Table 2).

For 2050, frontal erosion will result in only 6 to 13 m of shoreline retreat. Using the adjusted frontal erosion rate, shoreline retreat will be 2 to 3 times that amount with 22 to 46 m of retreat. The latter scenario will result in the berm migrating landward beneath the hotels. At this time, the sea will rise 57 cm higher than the present level and inundate 50 m of the present land surface during an 100-year storm.

By 2100, 40 to 140 m of shoreline retreat is projected to occur along this profile using the adjusted historical erosion rate. This will expose the houses along the profile to ocean waves as depositional environments retreat landward. Using the present historical erosion rate, only 11 to 39 m of shoreline retreat is expected. Even with these low projections, the hotels currently located behind the sand dike will be vulnerable to wave attack at this time. In addition, the expected 1.63 m of sea level rise will flood the first floor of every house surveyed along this profile and move landward the present A-zone upland boundary by 146 m.

A sediment-budget analysis of profiles modelled using the HEM method and the lower historical erosion rate showed material removed from sediment sources along the profile contributed only 47, 24 and 6 percent of the material required to produce the modelled changes landward of the dike for 2020, 2050 and 2100, respectively. The NAS-modelled profile changes revealed less of a sediment deficit with 100, 80 and 56 percent of the material required to produce the modelled changes for 2020, 2050 and 2100, respectively, coming from sediment sources along the profile. Using adjusted frontal erosion rates, source material removed will exceed the amount of sediment required to produce the modelled profiles for all scenarios except for the 2100 HEM scenario which will have a 39% sediment deficit. The 1990 and 2020 HEM projections will have 2.0 to 1.5 times more material removed from source areas than deposited along the modelled profile. The three NAS projections revealed 3 to 5.5 times as much removal versus deposition.

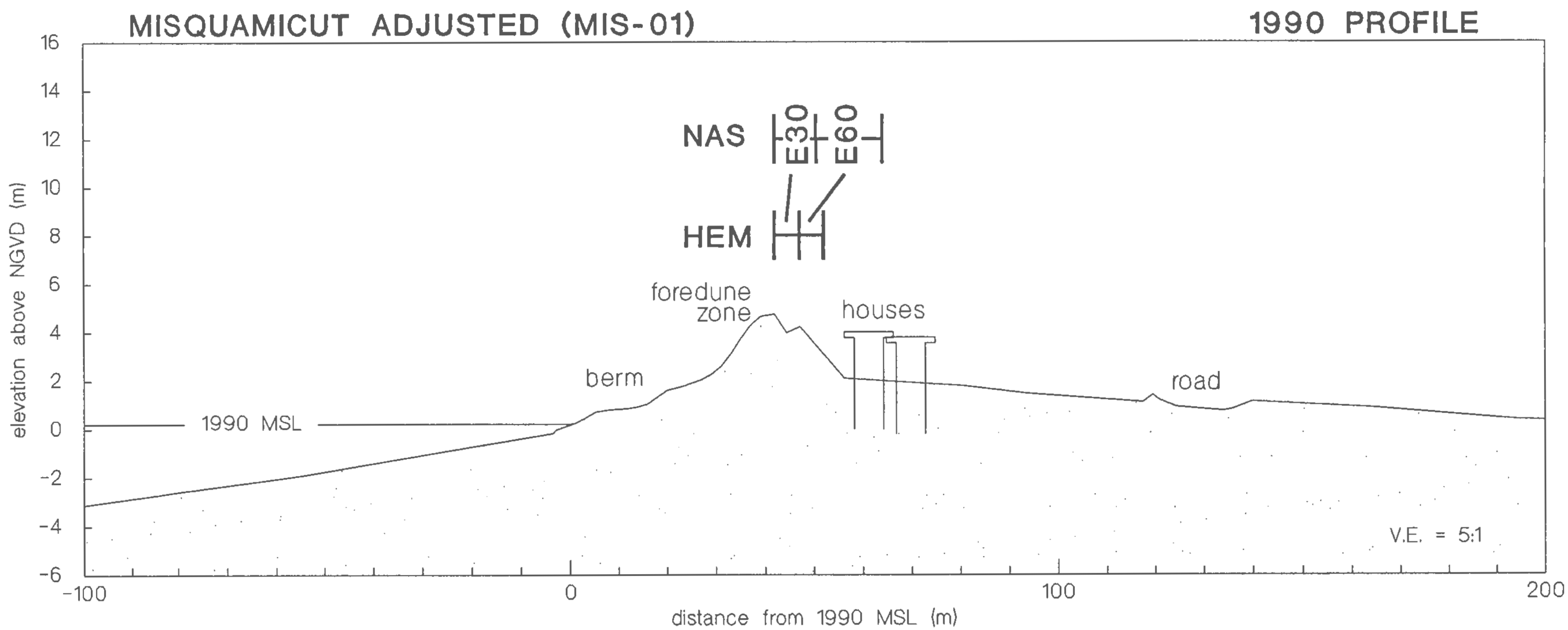
Misquamicut Barrier Profile (MIS-01)

This is one of three profiles in this study used by McMaster for his ongoing monitoring of shoreline changes (1961-present). This barrier profile is backed by Winnapaug pond and is located approximately 2.0 km east of Misquamicut State Beach (Figs. 14, 15 and 34). Only two houses, located within the foredune zone, exist along this profile. The

Figure 14. Location of Misquamicut (MIS-01) profile in Westerly. This barrier profile fronts Winnapaug pond. The only houses along this profile are located within the foredune zone.


MIS-01

Figure 15. Profile from Misquamicut (MIS-01) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. All measurements were made using an adjusted historical erosion rate as described in the text. The intermediate hazard zone was located 10 and 17 m landward of the foredune zone when calculated using the HEM and NAS method, respectively. The E-60 zone measured 21 and 44 m when calculated with the HEM and NAS methods, respectively.


MISQUAMICUT ADJUSTED (MIS-01)
1990 PROFILE
NAS
E30
E60
HEM
foredune zone
houses
berm
road
1990 MSL
V.E. = 5:1
elevation above NGVD (m)
distance from 1990 MSL (m)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-100
0
100
200

erosion rate at this site is low compared to adjacent transects (Boothroyd and others, 1988); therefore, two sets of profiles also were prepared for this site, using the same criteria for adjusting historical erosion rates as MIS-CR.

Thirty years of continued frontal erosion will result in this profile retreating only 4 to 6 m with a 22 cm rise in sea level. Adjusted frontal erosion rates will displace the shoreline landward 10 to 17 m. The present A-zone will extend landward only 2 m because of the steep slope of the upland on the backside of the lagoon.

By 2050, the shoreline will have retreated landward 8 to 16 m using current erosion rates. Using adjusted erosion rates, the shoreline will retreat 21 to 44 m. The latter scenario will result in the two houses being destroyed.

With an expected 1.56 m rise in sea level for 2100, this profile was projected to retreat between 14 and 51 m or 38 and 137 m using preadjusted and adjusted frontal erosion rates, respectively. An expected 100-year storm surge at this time will extend the A-zone landward by 51 m. The houses will be destroyed at this time if no action is taken to protect them.

Unlike the previous two sites, this profile was lacking available sediment from sources along the profile for every migration scenario. Scenarios using preadjusted erosion rates revealed 9 to 73 times more removed material from source areas would be needed to produce the modelled profile configurations for 2020 through 2100. The scenarios using adjusted rates of frontal erosion were less extreme. The HEM profiles showed deficits of removed source material ranging from 4 to 14 times, while NAS-modelled profiles showed deficits of approximately 2 times for 2020, 2050 and 2100.

East Beach Barrier Profile (EST-01)

This barrier profile, also monitored for shoreline changes by McMaster (1961-present), was the least disturbed barrier system analyzed. EST-01 is located approximately 0.6 km east of the East Beach parking lot and about 2 km west of the Charlestown breachway (Figs. 16, 17 and 35). The profile consists of a wide berm fronting low-lying dunes. Overwash deposits form the sandy backbarrier flat and the large subtidal surge platform that extends into Ninigret pond.

Modelled 2020 HEM and NAS profiles detail 14 and 22 m, respectively, of landward barrier and shoreline migration with a 22 cm rise in sea level. Storm surges from a 100-year storm event will inundate 9 m of upland backing the lagoon.

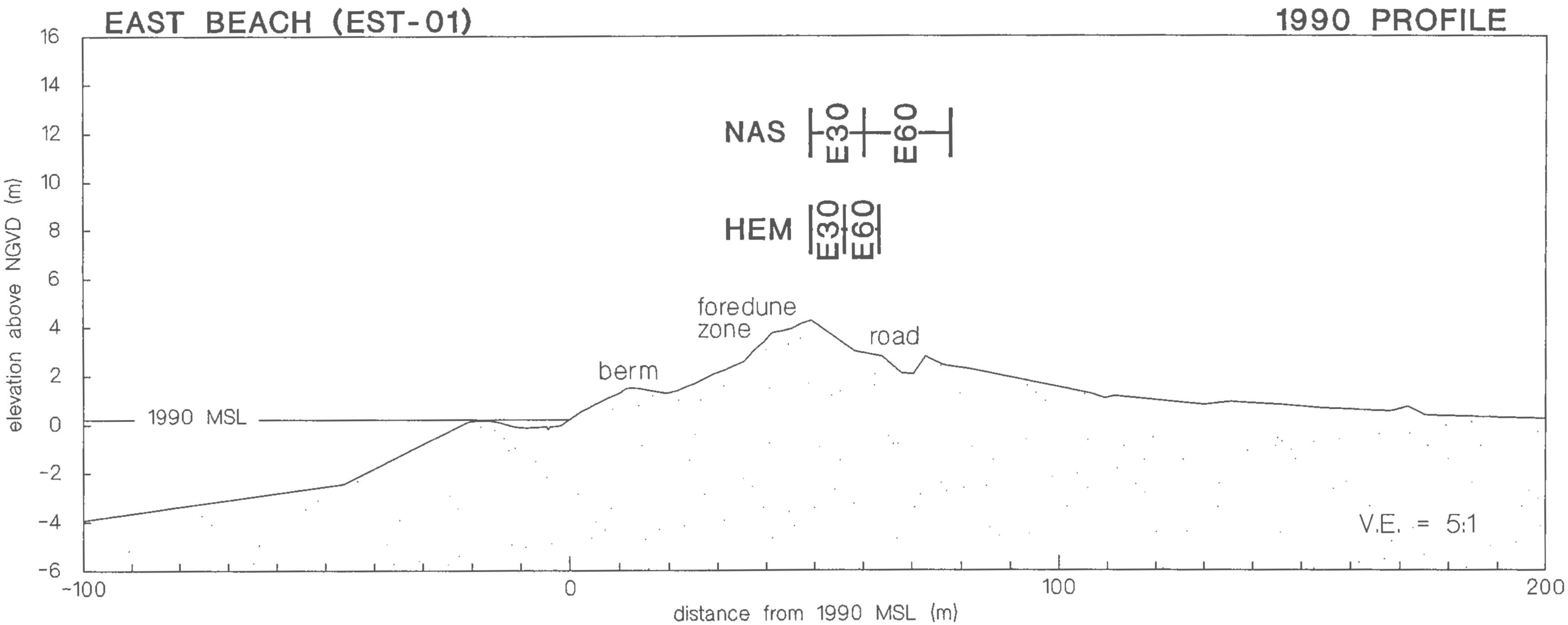
In 60 years, a 27- to 57-meter landward shift of the barrier and shoreline will occur, and the present A-zone will extend landward by 23 m.

By 2100, the barrier and shoreline will migrate landward between 50 and 175 m. The latter scenario will result in the barrier migrating over much of the present

Figure 16. Location of East Beach (EST-01) profile in Charlestown. This barrier profile is the only profile studied without structures. Ninigret pond is located behind the barrier.


EST-01

Figure 17. Profile from East Beach (EST-01) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. The E-30 zone calculated using the historical erosion method (HEM) measured 14 m. Using the NAS method, the E-30 zone measures 22 m. The E-60 zone measured 27 and 57 m when calculated with the HEM and NAS methods, respectively.


EAST BEACH (EST-01)
1990 PROFILE
NAS
E30
E60
HEM
E30
E60
foredune
zone
road
berm
1990 MSL
V.E. = 5:1
elevation above NGVD (m)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-100
0
100
200
distance from 1990 MSL (m)

storm surge platform. Storm surges are expected to increase the length of the present A-zone by 66 m at this time.

A sediment budget analysis for the NAS scenarios shows that 69 to 74 percent of the sediment required to produce the modelled profile configurations will be derived from offshore sediment sources. The HEM scenarios will require much more sediment to be transported from other areas beyond this profile as only 14 to 42 percent will be derived from within the profile system.

Charlestown Beach Barrier Profile (CHA-EZ)

Monitoring of shoreline changes has been conducted at this site by Boothroyd since 1977 (Boothroyd and others, 1981; Boothroyd and others, 1986; Boothroyd and others, 1988b). CHA-EZ is located approximately 0.5 km west of the Charlestown Town Beach accessway on the heavily populated Charlestown barrier (Figs. 18, 19 and 36). The profile traverses across many depositional environments, including washover deposits from the 1938 and 1954 hurricanes and the high and low marshes on the backbarrier.

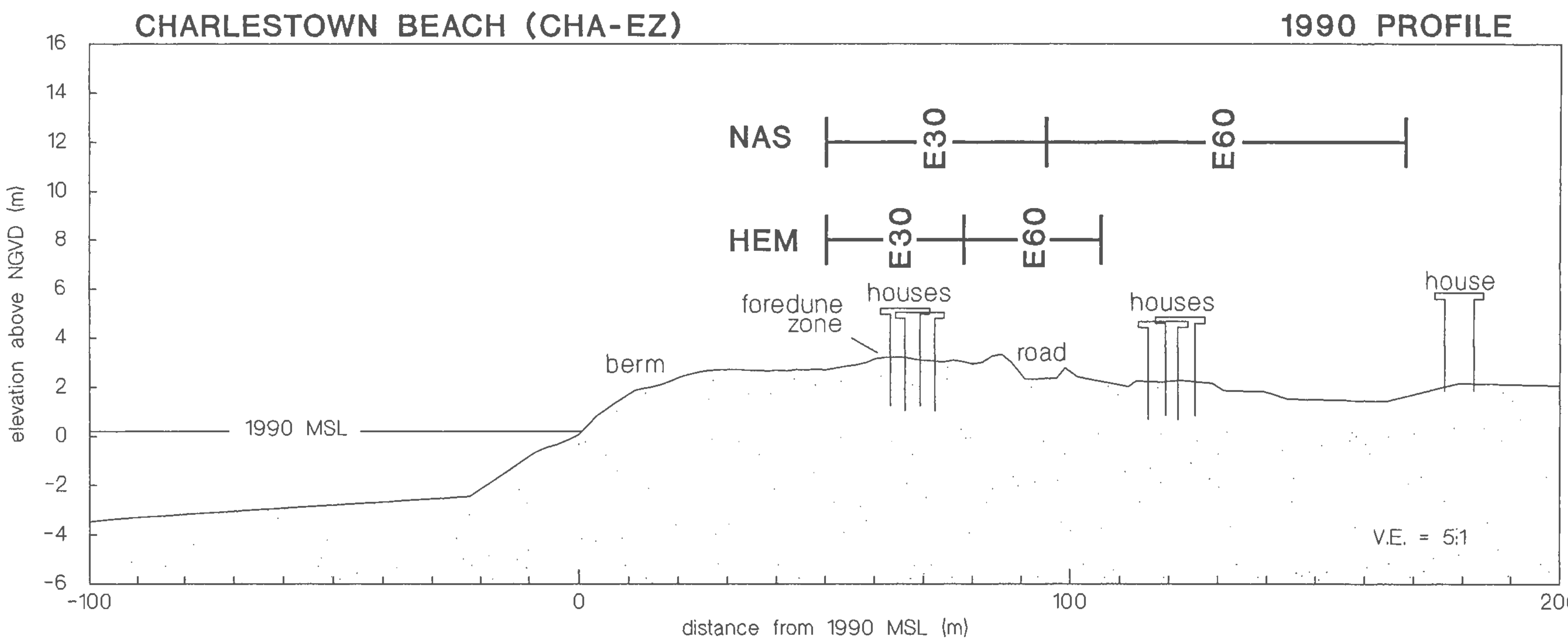
This profile has the highest historical frontal erosion rate (0.93 $m \cdot yr^{-1}$) of any studied (Boothroyd and others, 1988). This high rate of erosion will produce 28 to 45 m of barrier and shoreline migration in 30 years. The present A-zone will extend landward by 11 m at this time.

Continued migration at this site through 2050 will result in 56 to 118 m of frontal erosion. For the NAS

Figure 18. Location of Charlestown Beach (CHA-EZ) profile in Charlestown. This barrier profile fronts Ninigret Pond. All the structures on this barrier were built after 1963, years after the 1938 and 1954 hurricanes destroyed all the houses on the barrier.


CHA-EZ

Figure 19. Profile from Charlestown Beach (CHA-EZ) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. The E-30 zone calculated using the HEM measured 28 m. Using the NAS method, the E-30 zone measured 45 m. The E-60 zone measured 56 and 118 m when calculated with the HEM and NAS methods, respectively.


CHARLESTOWN BEACH (CHA-EZ)
1990 PROFILE
NAS
E30
E60
HEM
E30
E60
foredune
zone
houses
houses
house
berm
road
1990 MSL
V.E. = 5:1
elevation above NGVD (m)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-100
0
100
200
distance from 1990 MSL (m)

modelled profile the two seaward sets of houses will probably be destroyed as depositional environments migrate landward. The HEM modelled profile resulted in the seaward set of houses being exposed to wave attacks on the berm. The extension of the A-zone will be a modest 29 m at this time.

For 2100, the barrier and shoreline will retreat landward by 102 and 363 m. The latter NAS projection will result in all of the houses being destroyed as the berm retreats out onto the present-day marsh. The smaller HEM projection will result in first seaward set of houses being destroyed and maybe the second seaward set of houses too. With a 1.56 m rise in sea level coupled with a 100-year storm surge, all the first floors of the houses along this profile will be flooded.

Analyses of the sediment budget for the two different scenarios showed HEM modelled profiles having large deficits and NAS modelled profiles having small deficits of removed source material needed to supply modelled profile changes. Over the 110-year time period considered, the HEM modelled profiles showed a decrease in sediment supply from a high of 51 percent in 2020 to a low of 23 percent in 2100. The NAS modelled profiles showed only a 2 to 6 percent deficit.

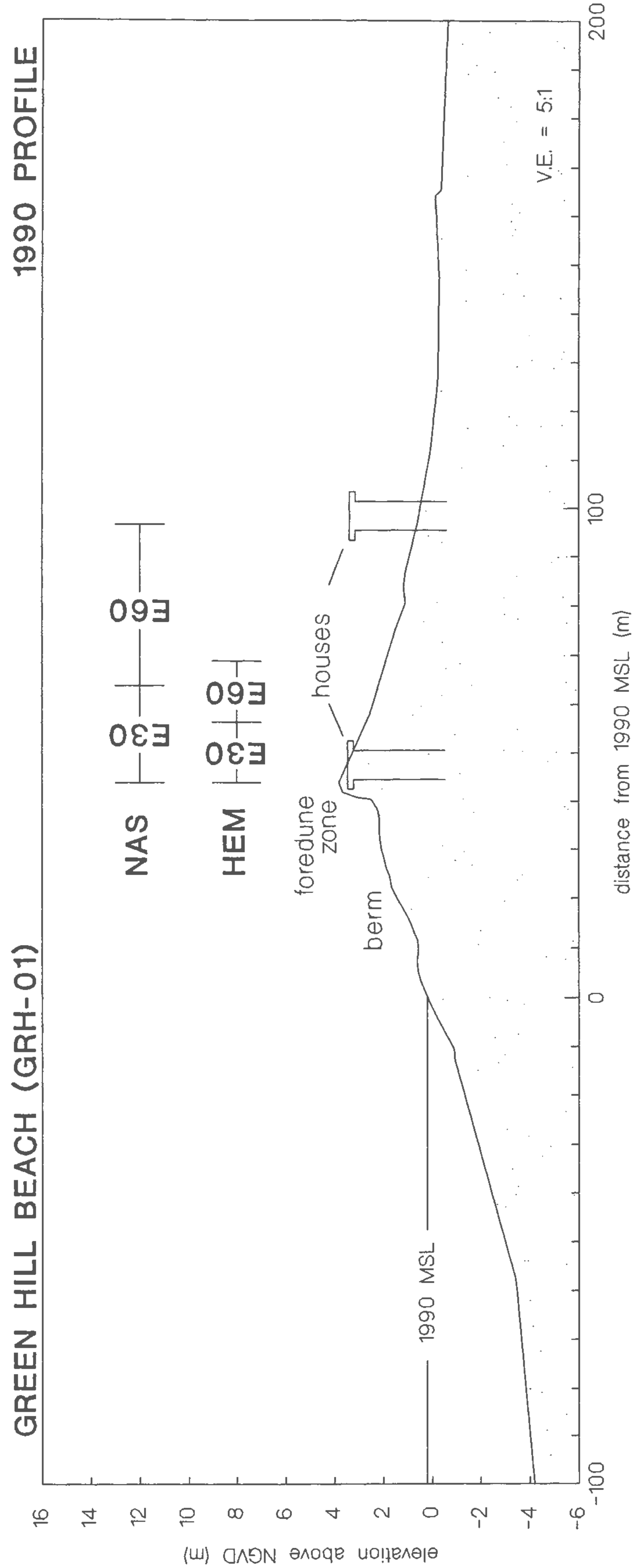
Green Hill Barrier Profile (GRH-01)

This barrier profile located just west of the Green Hill headland (Figs. 20, 21 and 37) is the last of

Figure 20. Location of Green Hill (GRH-01) profile in South Kingstown. This barrier profile fronts Trustom pond and is located close to the Green Hill headland.


GRH-01

Figure 21. Profile from Green Hill (GRH-01) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. The intermediate hazard zone measured 25 to 40 m when calculated using the HEM and NAS methods. The E-60 zone measured 50 and 106 m when calculated with the HEM and NAS methods, respectively.


GREEN HILL BEACH (GRH-01)
1990 PROFILE
NAS
HEM
E30
E60
houses
foredune
zone
berm
1990 MSL
V.E. = 5:1
elevation above NGVD (m)
distance from 1990 MSL (m)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-100
0
100
200

McMaster's monitored sites (1961-present) studied here. The profile exhibits a scarp at the frontal foredune and the backbarrier flat consists primarily of high marsh vegetation. Nearby to the east are two houses on pilings.

The historical frontal erosion rate for this barrier profile is also very high at 0.83 $cm \cdot yr^{-1}$ compared to other barrier segments along the southern coast (Boothroyd and others, 1988). In thirty years, 25 to 40 m of landward displacement of the shoreline and barrier will occur along with a 22 cm upward displacement. The upland boundary of the present A-zone will migrate landward by 18 m at this time.

In sixty years, the 50 to 106 m of landward migration of the depositional environments along this profile will result in the house closest to the shoreline being destroyed. The 57 cm rise in sea level will result in the present A-zone extending landward by 58 m.

In 2100, the barrier and shoreline will migrate landward by 91 to 324 m using the HEM and NAS migration methods, respectively. Both houses will be destroyed at this time. In addition, 100-year storm surges at this time will extend the present A-zone landward by 342 m. Removal of source material from the shoreface, berm and foredune zone along this profile will supply enough sediment to produce all the modelled profile configurations, except for the HEM 2100 profile. The HEM modelled profiles for 2020 and 2050 showed surpluses of 58 and 25 percent of removed source material. The 2100 projection showed a deficit of 28 percent. The NAS projections showed surpluses of 211 to 277 percent.

Matunuck Headland (S. Kingstown Town Beach) Profile (SKT-TB)

This headland profile is located just west of the new pavilion and approximately 0.4 km west-southwest of the intersection between Card's Pond road and Matunuck Beach road (Figs. 22, 23 and 38). The profile traverses across a wide, gently-sloping glacial fluvial surface which abruptly ends with an erosional scarp and is fronted by a steeply dipping berm.

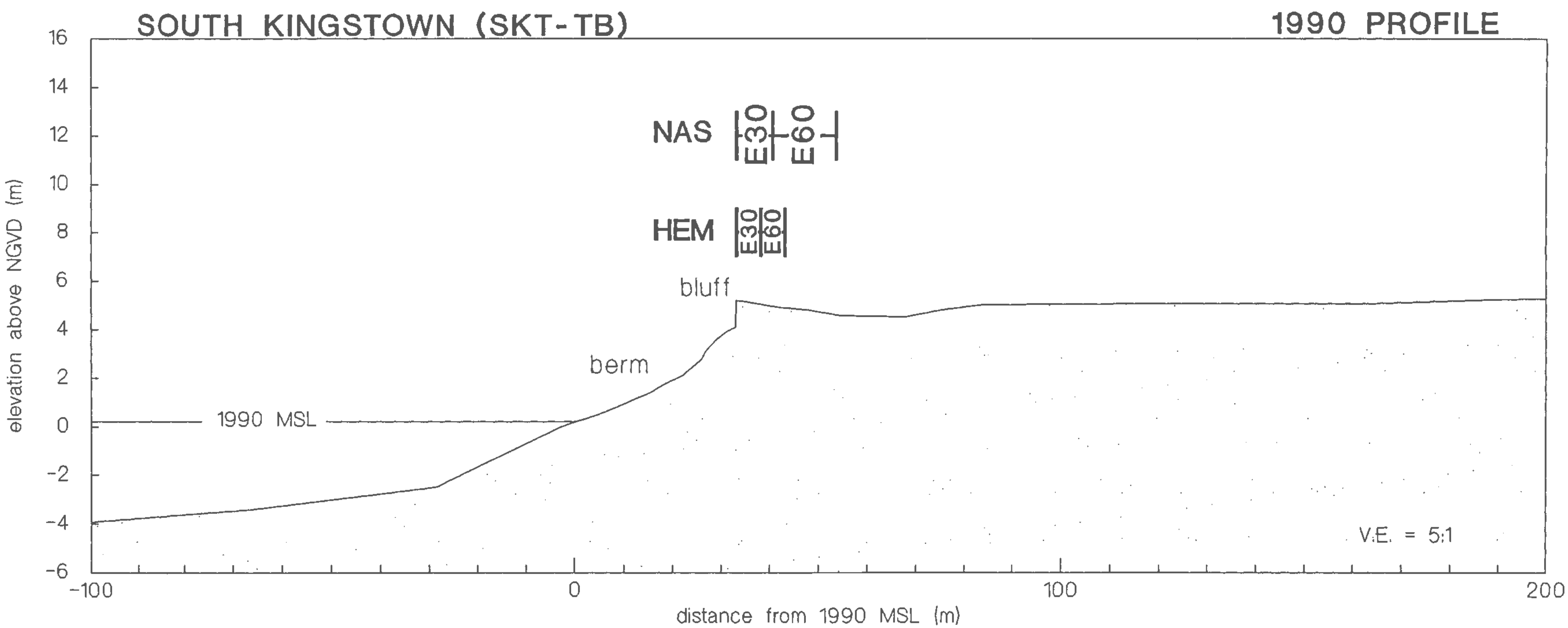
In 30 years, the erosional scarp will have retreated landward by 10 to 15 m using the HEM and NAS methods, respectively. No significant amount of sediment is expected to overtop the scarp, even during an 100-year storm event on top of the projected 22 cm rise in sea level. The back of the present FEMA A-zone will migrate landward by the same amount as frontal retreat. This will be the case for all migrations of the upland boundary of the A-zone at this site because the intersection of this boundary and the land surface is tied to the retreating bluff and not to a stationary upland surface.

By 2050, the erosional scarp will retreat by 19 to 41 m as the berm migrates upward 57 cm. And in 2100, 35 to 125 m of retreat will occur. The projected 1.56 m rise in sea

Figure 22. Location of South Kingstown Town Beach (SKT-TB) profile in South Kingstown. A new pavilion, not shown in this figure, is located just east of this profile.


SKT-TB

Figure 23. Profile from South Kingstown Town Beach (SKT-TB) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. The E-30 zone measured 10 and 15 m, and the E-60 zone measured 19 and 41 m when calculated using the HEM and NAS methods, respectively.


SOUTH KINGSTOWN (SKT-TB)
1990 PROFILE
NAS
E30
E60
HEM
E30
E60
bluff
berm
1990 MSL
V.E. = 5:1
elevation above NGVD (m)
distance from 1990 MSL (m)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-100
0
100
200

level at this time will allow for overtopping of the glacial fluvial surface, and dune formation will commence. The dunes for this profile were modelled using the dune configuration at the Watch Hill headland profile but scaled down in size by half because of the relatively short amount of time the dunes will have to form.

A sediment budget analysis for this site shows all migrations will generate enough sediment from sources along the profile to form the modelled profiles. For 2020 and 2050, all of the sediment eroded from the shoreface and bluff region will be transported elsewhere, since no deposition is expected to occur. By 2100, only 62 to 95 percent of the eroded sediment will be transported elsewhere as some sediment will remain to form the new dunes.

Point Judith Headland (Scarborough State Beach) Profile (SCA-SB)

This headland profile is located approximately 3 km north of the Point Judith Coast Guard Station along Ocean Drive (Figs. 24 and 39). The profile traverses across a wide berm that abuts against a seawall, continues landward from the top of the seawall through a walkway beneath the beach pavilion, crosses Ocean Drive, and ends on a small hill lined with houses. Erosion along this profile was modelled only for the area in front of the seawall because it was assumed that maintenance of the seawall would keep pace with future sea-level rise. In addition, the natural

Figure 24. Location of Scarborough State Beach (SCA-SB) profile in Narragansett. The only site with a seawall, the berm fronting this headland profile will continue to decrease in size as sea level rises. Route 1A is situated parallel to the coast.


SCA-SB

erosion rate of the area prior to the construction of the seawall was assumed to continue unabated based on studies by Dean (1985). Furthermore, no attempt was made to describe increased berm erosion caused directly by the seawall because of the lack of information at the site and within the coastal geology and engineering communities (Pilkey and Wright, 1988; Kraus, 1988). Erosion hazard zones were not calculated at this site because of the presence of the seawall. It was assumed that the state would maintain the seawall thus preventing any erosion landward of the seawall.

The historical frontal erosion rate for this site is 0.3 $m \cdot yr^{-1}$ (Dein, 1978). By 2020, this will result in the profile seaward of the seawall moving landward 9 to 18 m with a 22 cm rise in sea level. Almost all of the sediment removed from the shoreface and berm will be transported elsewhere (Table 1). Storm surges at this time will be above the seawall and will inundate the ground level of the pavilion. The A-zone will extend landward by only 4 m at this time.

A 57 cm sea level rise by 2050 will result in the shoreline retreating 18 to 49 m. If the latter scenario occurs, the berm will be less than 20 m wide at this time.

For 2100, the results from the two migration scenarios vary greatly. The HEM-modelled profile will retreat by 31 m and have a small berm with an elevation almost equal to the elevation of the top of the seawall. In contrast, the NAS-modelled profile will have no berm at all because the profile will migrate landward by 139 m, but the height of the sediment will be lower than the ocean at the base of the seawall. Storm surges from a 100-year event at this time will inundate the beach parking lot, the beach pavilion, and reach the south bound lane of Route 1A.

A sediment-budget analysis at this site reveals most of the sediment removed from the shoreface and berm will be deposited elsewhere due, in part, to the presence of the seawall.

Narragansett Barrier (Town Beach) Profile (NAR-TB)

Located next to the new beach pavilion approximately 0.5 km north of the intersection of Kingstown Road and Route 1A, this barrier profile is backed by Little Neck Pond (Figs. 25, 26 and 40). The seaward portion of the profile is characterized by a wide gently-sloping berm and beachface and relatively small foredune zone. Landward of the foredune zone and fronting Little Neck Pond is a parking lot for beach commuters. The slope of the parking lot was assumed to approximate the preexisting slope of this area when the profile was modelled. Backing Little Neck Pond is a steeply seaward-sloping till and bedrock hill (Schafer, 1961).

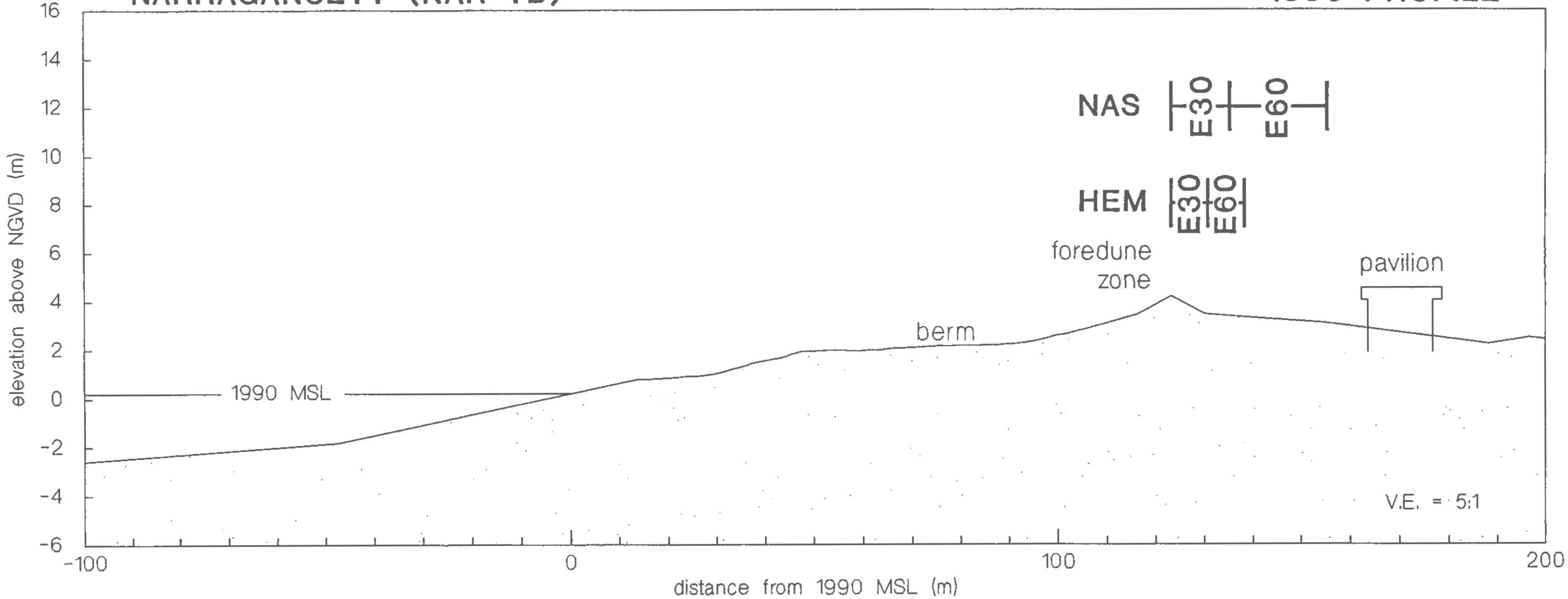
The historical frontal erosion rate at this site (-0.5 $m \cdot yr^{-1}$) (Dein, 1978) is low compared to the barriers along the Block Island coast (Boothroyd and others, 1988). With a projected 22 cm rise for 2020, this barrier and shoreline

Figure 25. Location of Narragansett Town Beach (NAR-TB) profile in Narragansett. This barrier profile fronts Little Neck Pond. No houses exist along this profile; however, it is a popular place for beachgoers and now has a new beach pavilion.


NAR-TB

Figure 26. Profile from Narragansett Town Beach (NAR-TB) showing intermediate (E-30) and long-term (E-60) erosion hazard zones. The E-30 zone calculated using the historical erosion method (HEM) measured 15 m. Using the NAS method, the E-30 zone measures 24 m. The long-term hazard zone measured 30 and 64 m when calculated with the HEM and NAS methods, respectively.

NARRAGANSETT (NAR-TB) 1990 PROFILE



will migrate landward by 15 to 24 m. The present A-zone will extend landward by only 3 m due to the steeply dipping till and bedrock hill.

A 57 cm rise in sea level and 60 years of erosion will result in 30 to 64 m of shoreline retreat at this site. At this time, Route 1A could be covered by washover deposits. Hurricane Bob of August, 1991 and the Halloween storm of 1991 have already deposited sediment onto Route 1A. Only 7 m of landward extension of the A-zone will occur at this time.

By 2100, 55 to 195 m of shoreline retreat will occur at this site. The HEM migration shows Route 1A and the pavilion being covered by encroaching dunes. If the NAS migrations occur, Route 1A and the pavilion will reside on the beachface.

A sediment budget analysis of this site reveals HEM migrated profiles for 2020 will show a projected 22 percent surplus of material eroded from the shoreface and berm. In contrast, the 2050 and 2100 modelled profiles show a 20 and 80 percent deficit of eroded material. Analysis of the NAS sediment budget reveals 290 to 570 percent more material will be eroded from the shoreface, berm and foredune zone than will be required for deposition.

DISCUSSION

Sea Level Rise

Many studies have documented global rises in sea level for the last 100 years (Redfield and Rubin, 1962; Barnett, 1983; Braatz and Aubrey, 1987; Gornitz and Lebedeff, 1987; Pirazzoli, 1989). Gornitz and Lebedeff (1987) have estimated the mean eustatic sea-level rise for the last century to be 1.2 ± 0.3 $mm \cdot yr^{-1}$. Locally, the relative sea-level rise rate is estimated to be 2.7 ± 0.2 $mm \cdot yr^{-1}$ with local subsidence considered.

Over the next 100 years, the rate of sea-level rise is projected to increase dramatically (Hoffman, 1984; Kerr, 1989; Houghton and others, 1990). From climate model studies, an expected doubling of greenhouse gasses could yield atmospheric temperature increases of 1.5° to 4.5°C for the next century (Charney, 1979; Smagorinsky, 1982; Hoffman and others, 1983; Hansen and others, 1984). Presently, visible light form the sun reaches the earth and is converted into infrared radiation, which then escapes back into space. Under greenhouse conditions, however, the buildup of gasses in the atmosphere can absorb the infrared radiation and raise global temperatures. Feedback mechanisms, such as decreased albedo and increased cloud cover, could further enhance temperature increase. This temperature increase will lead to greater thermal expansion of ocean waters, to partial melting of land-based glaciers, and to rapid calving and possible disintegration of tidewater glaciers.

In 1983, the Environmental Protection Agency (EPA) (Hoffman and others, 1983) developed four scenarios for future global sea levels by estimating the changes in atmospheric composition, relating these changes to global warming, and then determining the contributions of melting snow/ice and the expansion of ocean waters to eustatic sea levels. Estimates of changes in the atmospheric composition were based on projected emissions of the greenhouse gasses. For CO_2 estimates, projections of future economic growth and fossil fuel use were made. Parameters defining economic growth and fossil fuel use - worldwide population growth, productivity growth, energy production technologies, fossil energy resources, and energy use - were then integrated into a world energy model. The resulting projections of CO_2 were then placed in a carbon cycle model to determine the amount of CO_2 remaining in the atmosphere. For the other "greenhouse" gasses (chlorofluorocarbons, nitrous oxides and methane), the process of projecting the airborne concentrations was less sophisticated than for determining CO_2 concentrations. Results of all the projections were increases in atmospheric gas concentrations over time.

With increased concentrations of greenhouse gasses that absorb infrared radiation, temperatures are expected to rise. The "low" scenario is estimated to increase present temperatures by 1.5°C with a CO_2 doubling. The "mid-range" scenarios use a temperature increase of 3.0°C. The "high" scenario projects temperatures increasing by 4.5°C. By comparison, during the warmest part of the present interglacial period between 5,000 and 6,000 years ago, the temperature was 1.0° to 2.0°C warmer than today (Houghton and others, 1990). Perhaps the warmest time during the Phanerozoic was the Cretaceous Period where temperatures were 6-11°C warmer than today (Barron and others, 1981).

Some of the consequences of a warmer climate are the expansion of ocean waters and the melting of glaciers. Oceans act as heat sinks by absorbing and diffusing the heat through the upper layers of the ocean. To predict how the oceans will react to the increased heat, Hoffman and others (1983) determined variable heat diffusion rates for the four scenarios using a simple diffusion box model. To determine the amount of water from melting glaciers contributing to future sea level rise, high and low ratios of ice and snow contributions were derived. These ratios were developed by different estimates of high and low historical sea level rise with a single estimate of past thermal expansion.

The results of the EPA project and local sea-level projections are summarized in Table 3. Local projections of sea level elevations for 2020, 2050 and 2100 were based on the "mid-moderate" scenario because this scenario more closely approximates the 25 to 40 cm rise estimates for 2050

TABLE 3. ESTIMATED EUSTATIC AND LOCAL SEA LEVEL PROJECTIONS ABOVE 1980 MEAN SEA LEVEL (in centimeters)

	EUSTATIC SCENARIOS				LOCAL SCENARIOS	
		Mid-Range Scenarios				
Year	Conservative	Moderate	High	High	Historical Extrapolation	Mid-Moderate
2020	11.2	22.2	33.2	45.5	24.4	42.2
2050	23.8	52.3	78.6	116.7	32.1	76.8
2100	56.2	144.4	216.6	345.0	46.9	176.4

determined by more recent studies (Kerr, 1989; Houghton and others, 1990).

Caution must be used when projecting future eustatic sea-level change. Projections of eustatic sea level caused by greenhouse gasses are constantly being reviewed and updated (Hoffman, 1984; Kerr, 1989; Meier, 1989; Houghton and others, 1990). The multitude of interrelated variables and feedback mechanisms used in climate modelling and in estimating future eustatic sea level has made it difficult to accurately predict the effects of proposed increases of "greenhouse" gasses on future global sea level. These difficulties should not, however, be misconstrued as evidence against future sea-level rise. Most scientists today believe that the climate is warming and that eustatic sea level will rise (Peltier and Tushingham, 1989; Pirazzoli, P.A., 1989; Meier, 1989; Houghton and others, 1990).

100-Year Storm Event

During the Great New England Hurricane of 1938, the 100-year storm of record, winds speed measured up to 242 kph (150 mph) and storm surge reached elevations of 3.0 to 4.6 m along the Rhode Island coast, causing extensive property damage as well as eroding and modifying headlands, beaches, the foredune zone, backbarrier flats, marshes and lagoons (Nichols and Marston, 1939). The storm surge, defined as the difference between storm elevated water level and normal astronomical tide level, was a result of a drop in barometric pressure, coastal water setup from onshore winds pushing ocean waters landward, and the path and timing of the hurricane. Future hurricanes of similar wind magnitude may be more or less severe than the 1938 hurricane, depending on the timing, path, and speed of the storm.

The impact of 3 to 4 m storm surge topped with 9 m waves was great on the configuration of local shorelines during the 1938 hurricane and devastating to local communities. Nichols and Marston (1939) estimated foredune retreat of as much as 50 m. Unfortunately, no values exist for the amount of berm removal from the 1938 hurricane; although it is assumed that the berm was removed, resulting in a "no-berm" condition. Since 1977 the four largest storms at the CHA-EZ profile have averaged 43 $m^3 \cdot m^{-1}$ of berm removal. In this study, the average modelled foredune retreat is 36 m and the average modelled amount of removed berm material is 50 $m^3 \cdot m^{-1}$ for a comparable 100-year storm event. Figure 6 shows modelled berm and dune erosion at the CHA-EZ profile. At this site, the foredune zone will retreat about 44 m and the berm will lose approximately 46 $m^3 \cdot m^{-1}$ of sediment.

FEMA Flood Zones

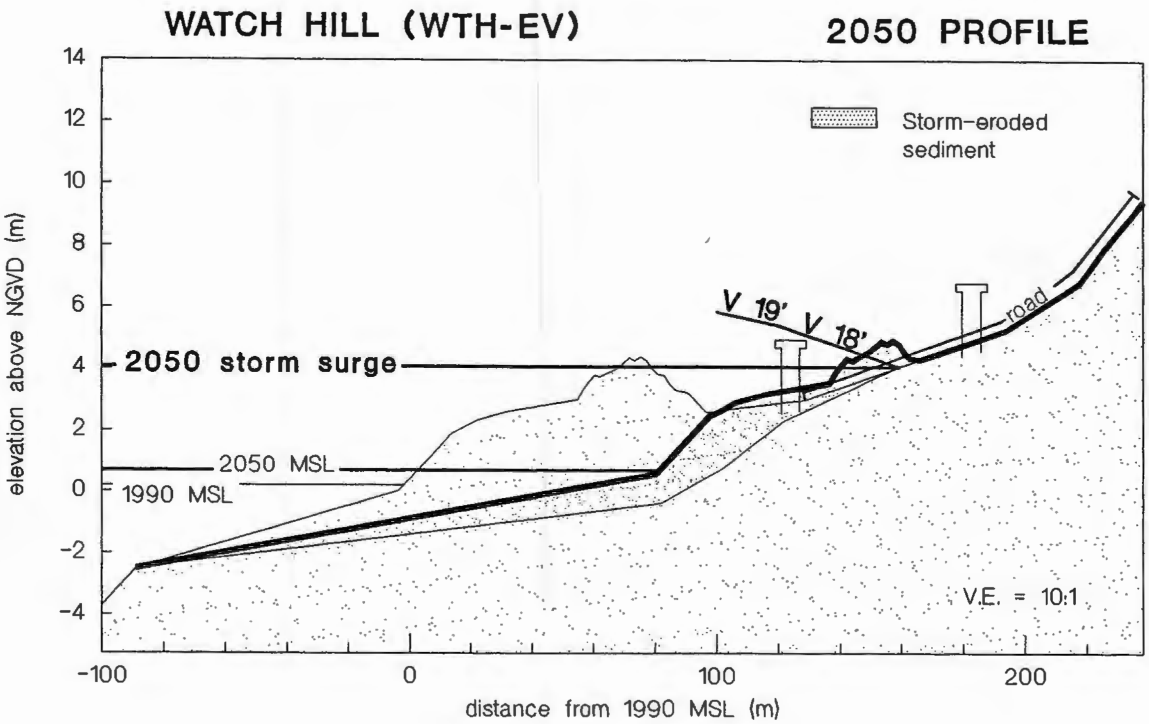
With an expected rise of 1.56 m by 2100, profile analysis reveals a landward shift of FEMA V/A boundaries of up to 362 m and a landward shift up to 345 m of the upland boundary of A-zones by 2100. Along the WTH-EV profile, the V/A flood zones will decrease in total length as the headland retreats, sea level rises and the back of the A-zone intersects the steeply sloping Charlestown Moraine. By 2050, the first floor of the house at the base of the end moraine will be flooded. By 2100, flooding will occur half way up the profile (Fig. 27). In Misquamicut, all the houses on Crandall Avenue profile (MIS-CR) could be flooded by an 100-year storm event in 2100. In Charlestown and Green Hill, all the houses presently on the barrier will be flooded by an 100-year storm event by 2100 (Fig. 28).

Barrier Migration and Headland Retreat

As sea level rises the area of wave energy expenditure is raised relative to the slope of the land surface. This may lead to increased frontal erosion and the migration of headlands and barrier systems caused by storm-surge and waves, resulting in washover and tidal-delta sedimentation (e.g., Godfrey and Godfrey, 1973; Leatherman, 1979; Scott and others, 1987; Kelley and others, 1988; Pilkey and others, 1989). In Rhode Island, Dillon (1970) first suggested that the Charlestown barrier had migrated by overwash processes during past rises in sea level. Other

Figure 27. Profile from Watch Hill (WTH-EV) showing NAS (1990) projected locations for 2050 and 2100. Modelled profiles are shown in bold.

NAS PROJECTIONS AT WTH-EV



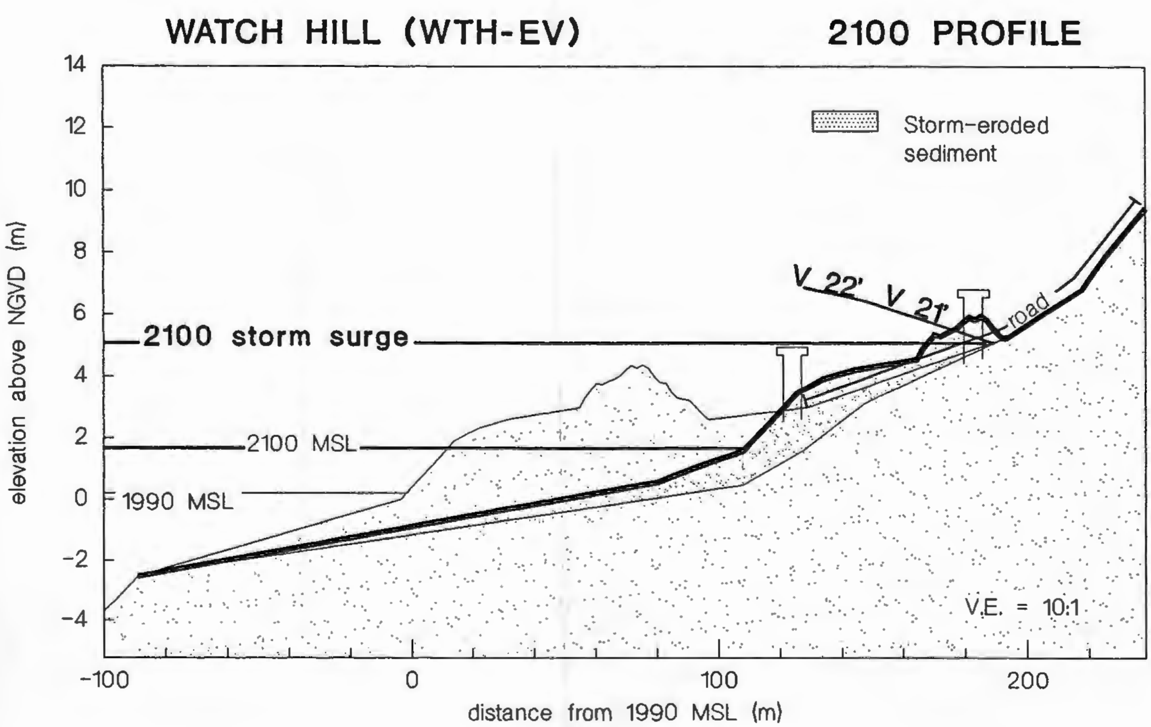
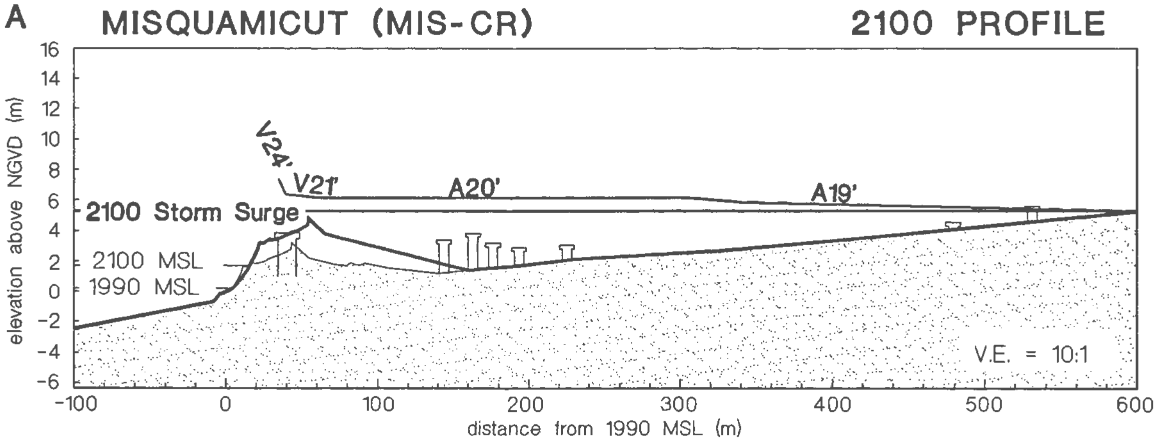


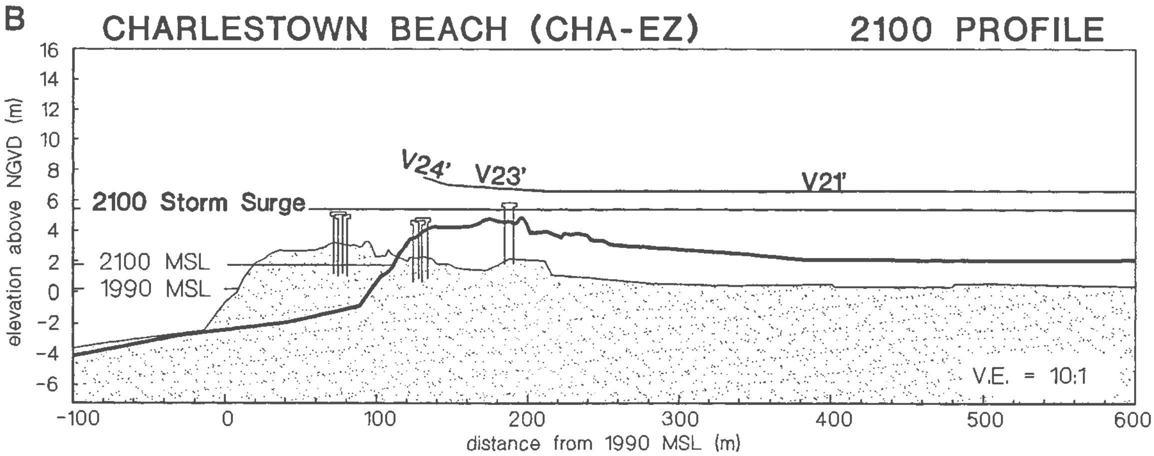
Figure 28. Historical erosion method (HEM) projections for 2100 showing houses on three different profiles being covered by a 100-year storm event. A) Profile from Misquamicut (MIS-CR) showing little migration due to the presence of a sand dike. B) Profile from Charlestown (CHA-EZ). C) Profile from Green Hill (GRH-01).

HEM PROJECTIONS FOR 2100

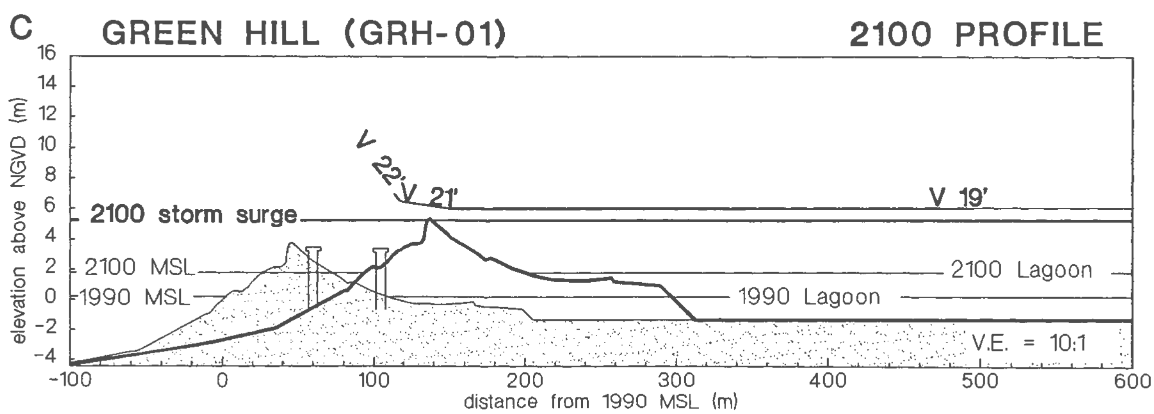
A



B



C



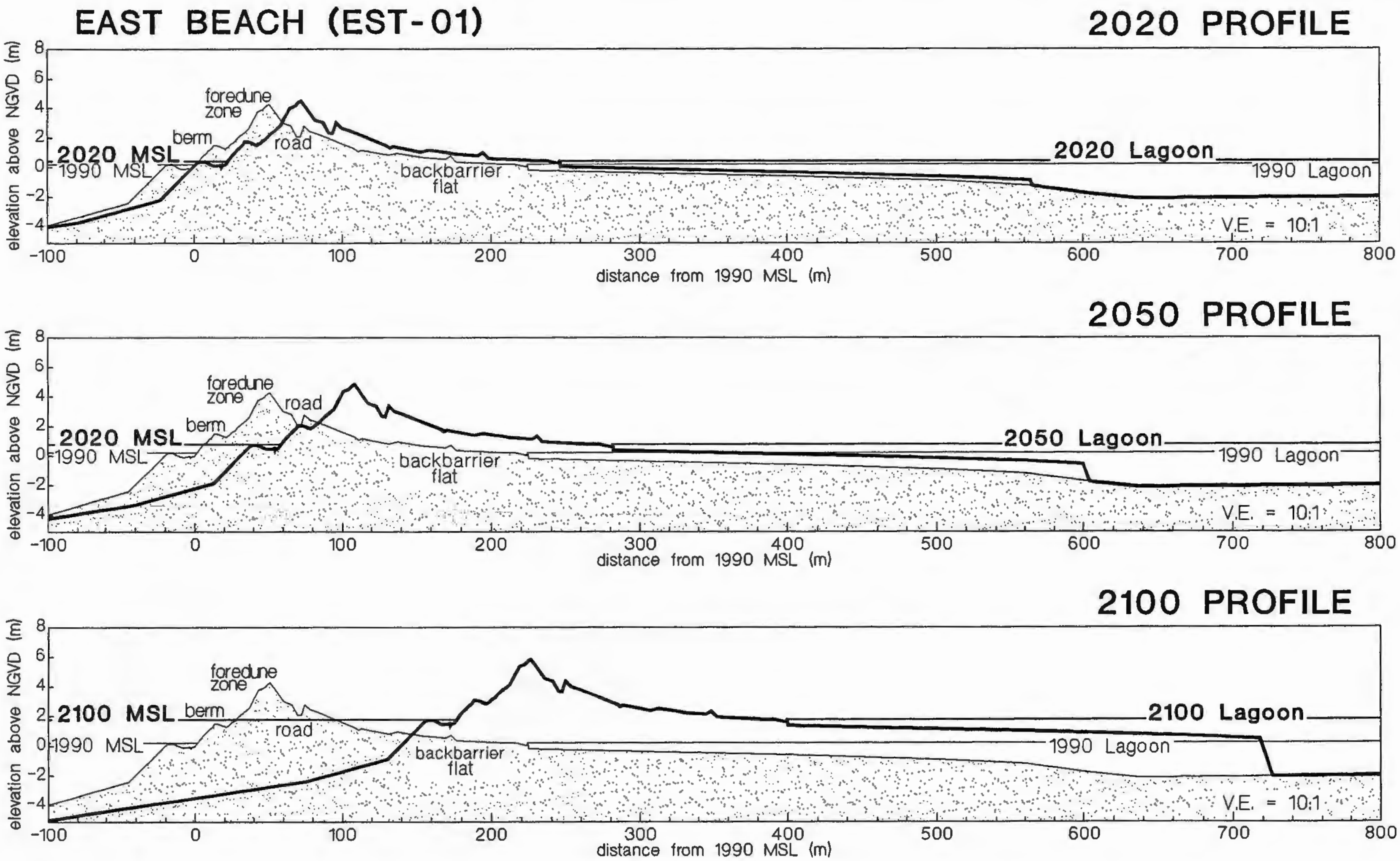
workers (Fisher and Simpson, 1979; Boothroyd and others, 1985; McGinn, 1982; and Dacey, 1989) have also studied the past landward migration of Rhode Island barriers and headlands. However, only McGinn (1982) and Dacey (1989) have described, if only briefly, future migration.

This study reveals significant changes in profile configurations over the geologically short time span of 110 years as sea level is projected to rise at a more rapid rate than in the recent past. Figure 29 shows the change projected to occur along the relatively undisturbed EST-01 profile on the East Beach barrier. Within 30 years, the foredune zone will migrate landward over the present-day backbarrier flat as the profile retreats between 14 and 22 m. By 2050, waves will have eroded between 27 and 57 m of the present shoreline as the profile also shifts upward by 57 cm due to rising sea level. And by 2100, the present-day barrier will have "rolled over" itself as the ocean transgresses 50 to 175 m landward and rises 1.56 m above present level. The foredune zone will be located at the 1990 barrier/lagoon edge and the backbarrier flat will occupy the location of the present-day storm surge platform.

A present-day analog for the impending transgression by the ocean of the barriers and low-lying headlands in Rhode Island may be found in Louisiana. Penland, Suter and Boyd (1985) have documented the retreat of Isles Dernieres, a barrier island arc, that has experienced an average relative rate of sea-level rise comparable to what is projected for

Figure 29. Profile from East Beach (EST-01) showing projected changes over the next 110 years using the NAS (1990) method.

NAS PROJECTED CHANGES AT EST-01



Rhode Island in the next century. Similarities of hydrologic and geologic conditions between Rhode Island and Isles Dernieres include: a) both are microtidal; b) both are affected by hurricanes and extratropical storms; and c) both lack any significant riverine sediment supply source. Thus, Rhode Island barriers and low-lying headlands may be expected to respond in a similar manner to an increase in sea level.

Sediment Budget Analysis

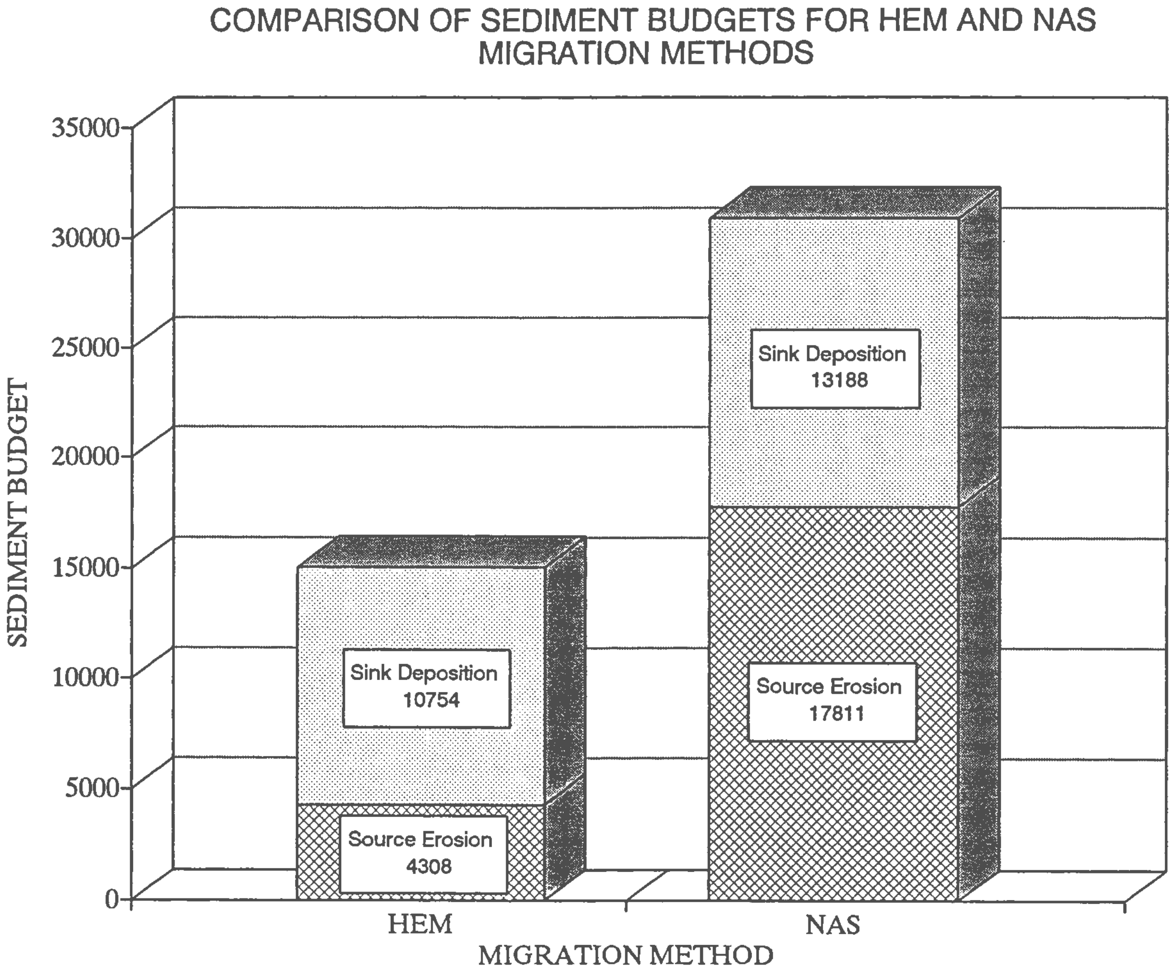
Projecting barrier migration and headland erosion requires that enough sediment be available to produce the new profile configuration generated. Dillon (1970) suggested that the Charlestown barrier has migrated landward by overwash processes during submergence because of its small size. He further suggested that the washover sediment was derived from the eroding shoreface. Williams and Meisburger (1987) have reported the shoreward transport of sand from the Long Island shoreface to local beaches. Kraft and others (1987) have proposed a similar scenario for sediment distribution during the Holocene Epoch for the transgressive Delaware coast.

One of the goals of this study was to determine if enough sediment would be available from offshore sediment sources along a profile to produce the modelled changes determined using the HEM and NAS migration methods. Comparing the results of the two methods revealed significant differences in terms of sediment availability (Table 1). At Watch Hill, both methods showed more material from sediment sources will be removed than will be needed to produce the modelled profiles. However, the NAS modelled profile showed seven times more sediment will be available for alongshore transport than the HEM modelled profile in 2100. In contrast, the 2100 EST-01 barrier profiles showed a net deficit of removed source material. But again, the NAS modelled profile had more available source sediment than the HEM migration - almost 5 times as much. If the amount of source material removed and the amount of material required to produce the modelled profiles for each scenario are added, the conservative historical erosion method yields only 40% of the sediment needed to produce the projected profile configurations, a deficit of 6446 $m^3 \cdot m^{-1}$. In contrast, the NAS method projects a 26% surplus, or 4623 $m^3 \cdot m^{-1}$, of sediment (Fig. 30).

The large sediment budget deficit of the HEM-modelled profiles is a major drawback for using the historical erosion method for approximating future shoreline positions. The NAS-modelled profiles have no sediment budget problems. Thus, assuming sea level rise rates will increase in the near future as predicted, the NAS method should be used to project future shoreline positions.

Another approach to projecting future migrations and shoreline positions is a sediment budget approach where the amount of erosion equals the amount of deposition along a

Figure 30. Sediment budget comparison between the two migration methods used in this study. The cross-hatched pattern is the amount of erosion projected to occur and the light dot pattern is the amount of projected deposition needed to produce new profile configurations. The NAS method shows a more equitable distribution of eroded to deposited sediment compared to the HEM.


COMPARISON OF SEDIMENT BUDGETS FOR HEM AND NAS
MIGRATION METHODS
35000
30000
25000
20000
15000
10000
5000
0
SEDIMENT BUDGET
Sink Deposition
13188
Source Erosion
17811
Sink Deposition
10754
Source Erosion
4308
HEM
NAS
MIGRATION METHOD

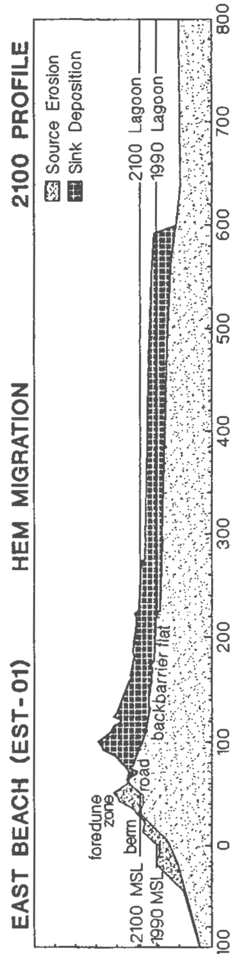
profile. This approach is illustrated in Figure 31 using CHA-EZ and EST-01 HEM 2100 profiles. The shape of the profiles was based on field observations made after a series of major storms struck the southern Rhode Island coast during the fall of 1991 and from analyzing the data from the monitoring of shoreline changes at CHA-EZ by Boothroyd since 1977 (Boothroyd and others, 1981; Boothroyd and others, 1986; Boothroyd and others, 1988b). Overwash processes from the storms of 1991 lowered the elevation of the foredune zone along the CHA-EZ profile and distributed the sediment landward as a series of wedged-shaped surge platforms. This process should intensify in the future as storms of similar magnitude will occur more frequently due to sea level rising (Galagan, 1990).

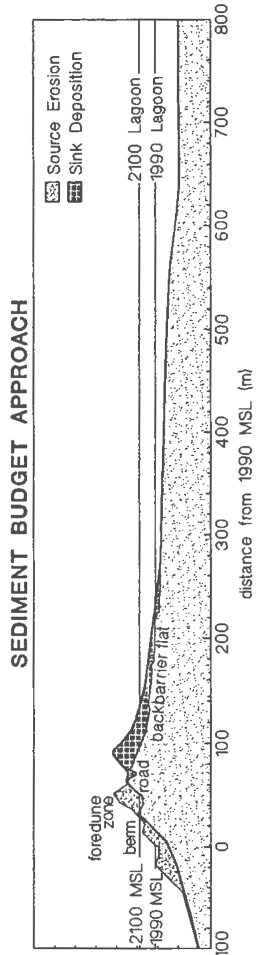
Management Strategies

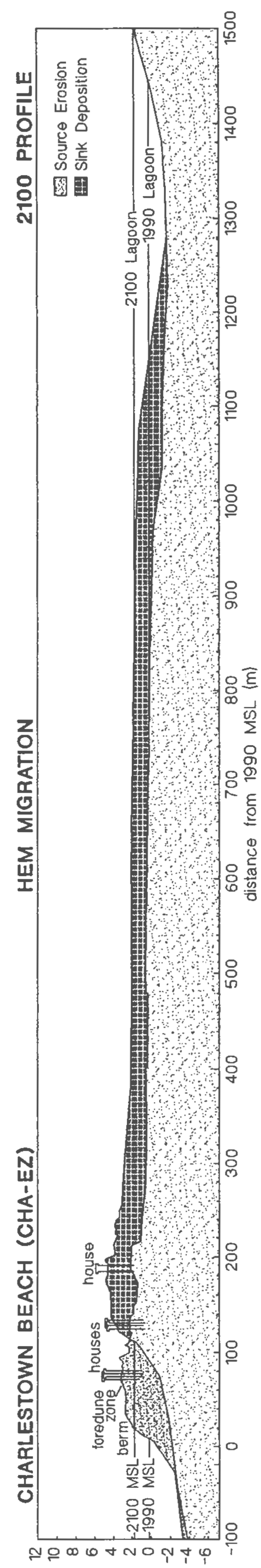
Present Rhode Island legislation (CRMC, 1983) regarding (setback) distances (Section 140) and construction of coastal structures (Section 300.3) will become inadequate over the next 110 years as sea level rises. Present legislation is based on historical erosion rates and does not consider sea level rise. As shown previously, significant changes are projected to occur along the coast with rising sea level over the next century.

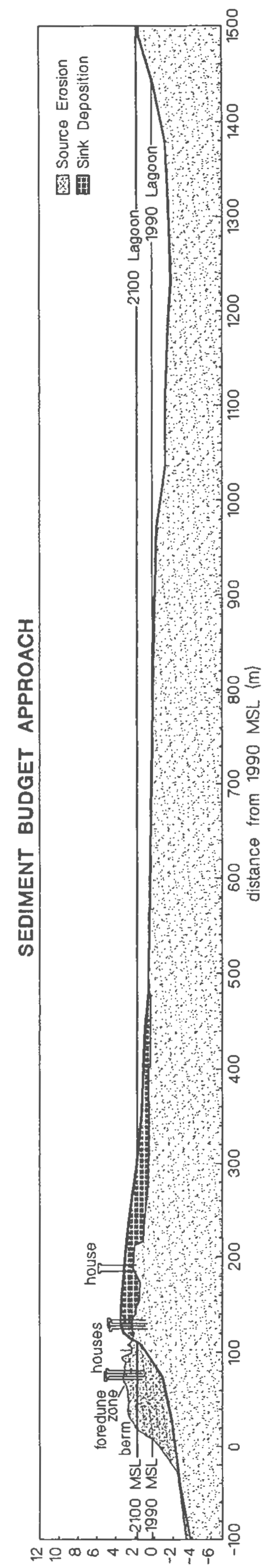
Current setback distances for critical erosion areas are determined by multiplying the historical erosion rate by 30, and areas not considered critical erosion areas have

Figure 31. Modelling CHA-EZ and EST-01 2100 HEM profiles using a sediment budget approach. Sediment deposited on EST-01 and CHA-EZ using the sediment budget approach is much smaller in volume compared to the modelled deposition of this study. The EST-01 and CHA-EZ profiles are lower in elevation and much narrower when modelled with the sediment budget approach than the methods employed in this study.


EAST BEACH (EST-01)
HEM MIGRATION
2100 PROFILE
Source Erosion
Sink Deposition
2100 MSL
1990 MSL
berm
foredune zone
road
backbarrier flat
2100 Lagoon
1990 Lagoon
elevation above NGVD (m)
distance from 1990 MSL (m)


SEDIMENT BUDGET APPROACH
Source Erosion
Sink Deposition
2100 MSL
1990 MSL
berm
foredune zone
road
backbarrier flat
2100 Lagoon
1990 Lagoon
elevation above NGVD (m)
distance from 1990 MSL (m)


CHARLESTOWN BEACH (CHA-EZ)
HEM MIGRATION
2100 PROFILE
Source Erosion
Sink Deposition
2100 MSL
1990 MSL
berm
foredune zone
houses
house
2100 Lagoon
1990 Lagoon
elevation above NGVD (m)
distance from 1990 MSL (m)


SEDIMENT BUDGET APPROACH
Source Erosion
Sink Deposition
2100 MSL
1990 MSL
berm
foredune zone
houses
house
2100 Lagoon
1990 Lagoon
elevation above NGVD (m)
distance from 1990 MSL (m)

setback distances of 50 feet (CRMC, 1983). In 1990, the National Academy of Sciences recommended to FEMA/FIA to delineate erosion hazard zones (E-zones) along eroding coastlines using the NAS (1990) method already described. This method differs from the historical erosion method (HEM) employed by CRMC (1990), as previously shown. These erosion zones will change, however, as the reference points (frontal foredune crest/bluff) retreat over time. I believe erosion hazard zones and the migration changes of these erosion hazard zones should be incorporated into future coastal legislation.

Future inundation should also be considered by the Coastal Resources Management Council (CRMC) for developing setback distances and minimum building elevation requirements. With rising water level and changes in storm frequency (Galagan, 1990), present legislation using static water level underestimates future conditions and should be rectified.

CONCLUSIONS

1. Sea-level rise projections for Rhode Island indicate a 156 cm rise in sea level from 1990 to 2100, almost four times greater than the amount determined by extrapolating historical sea level rise rates to 2100.

2. The average amount of modelled berm and foredune zone erosion caused by an 100-year storm event for all coastal profiles is 50 $m^3 \cdot m^{-1}$ and average foredune retreat is 36 m.

3. Over the next 110 years (2100), FEMA A-zones will shift landward up to 345 m. Most houses surveyed will be flooded at this time.

4. Dramatic changes to profile configurations are projected to occur as barriers migrate and headlands retreat landward up to 345 m and vertically by 1.56 m by 2100. Average barrier migration for 2100 was 75 and 265 m using HEM and NAS migration projections, respectively. Headland retreat for 2100 was 44 m using HEM projections and 114 m using NAS projections.

5. A sediment budget analysis reveals that the NAS (1990) migration method may be more suitable for projecting future migration and shoreline position. The NAS migration method

projects a 26% surplus of available sediment; whereas, the HEM migration method projects a 60% deficit.

6. Rhode Island CRMC legislation (1983) should be modified to include: 1) the most recent and widely accepted projections for future rising sea level; and 2) revisions to present setback distances. Increasing inundation should be considered for providing minimum flood elevations for structures within FEMA V and A flood zones. Setback distances currently used by CRMC (1983) need to be modified using the NAS (1990) method and inundation level. Figures depicting erosion zones (E-zones) should be incorporated into CRMC legislation for all sites along the Rhode Island coast.

REFERENCES CITED

Autodesk Inc., 1990, AutoCAD Release 11 software and Reference Manual: Autodesk Inc., 640 p.

Barnett, T.P., 1983, Recent changes in sea level and their possible causes: Climate Change, v. 5, p. 15-38.

Barron, E.J., Thompson, S.L., and Schneider, S.H., 1981, An ice-free Cretaceous results from climate model simulators: Science, v. 212, p. 501-508.

Boothroyd, J.C., Cable, M.S., O'Brien, J.H., McCreery, C.J., and Russell, F.D., 1978, Beach erosion and recovery: Charlestown, Rhode Island: *in* Jones, J.R., ed., The Blizzard of 1978: Its Effects on the Coastal Environments of Southeastern New England, Boston State College, p. 81-90.

Boothroyd, J.C., Friedrich, N.E., McGinn, S.R., Schmidt, C.A., Rosenberg, M.J., Peters, C.R., O'Brien, J.H., and Dunne, L.A., 1981, The geology of selected microtidal lagoons, Rhode Island, v. I & II: Technical Report No. 2-SRG, Department of Geology, University of Rhode Island, Kingston, Rhode Island, 576 p.

Boothroyd, J.C., Friedrich, N.E., and McGinn, S.R., 1985, Geology of selected microtidal lagoons: Rhode Island, *in* Oertel, G.F., and Leatherman, S.P., eds., Barrier Islands: Marine Geology, v. 63, p. 35-76.

Boothroyd, J.C., 1985, Geologic processes pose problems for the Rhode Island shore: Maritimes, v. 29, no. 2, p. 1-3.

Boothroyd, J.C., Gibeaut, J.C., Dacey, M.F., 1986, Geological aspects of shoreline management: a summary for southern Rhode Island, I. Regional depositional systems and a long-term profiling network, Vol. 1: Technical Report No. 6-SRG, University of Rhode Island Sea Grant Final Report, Contract No. NA85AA-D-SG094, Project No. R/CS-1, 104 p.

Boothroyd, J.C., Galagan, C.W., and Graves, S.M., 1988a, Advance and retreat of the southern Rhode Island shoreline, 1939-1985: including 1985 berm volume: Technical Report No. 7-SRG, Sea Grant College Program, University of Rhode Island, Contract No. NA85AA-D-SG094, Project No. R/CR-871, 92 p.

Boothroyd, J.C., Graves, S.M., and Galagan, C.W., 1988b, The Rhode Island long-term beach profile network: 1986-1988 data: Technical Report No. 7-SRG, Sea Grant College Program, University of Rhode Island, Contract No. NA85AA-D-SG094, Project No. R/CR-871, 119 p.

Borland International Inc., 1991, Quattro Pro Release 3.0 software and Reference Manual: Borland International Inc., 807 p.

Braatz, B.V., and Aubrey, D.G., 1987, Recent relative sea-level change in eastern North America, *in* Nummedal, D., Pilkey, O.H., and Howard, J.D., eds., Sea-level fluctuation and coastal evolution: Society of Economic Paleontologists and Mineralogists Special Publication No. 41, p. 29-46.

Bruun, P., 1954, Coastal erosion and development of beach profiles, Beach Erosion Board Technical Memorandum No. 44: Washington, D.C., U.S. Army Corps of Engineers.

Bruun, P., 1962, Sea-level rise as a cause of shore erosion: Proceedings of the American Society of Civil Engineers: Journal of the Waterways and Harbors Division, v. 88, no. WWI, p. 117-130.

Charney, J., chairman, Climate Research Board, 1979, Carbon dioxide and climate: A scientific assessment/Report of an ad hoc group on carbon dioxide and climate, Woods Hole, MA, July 23-29, 1979 to the Climate Research Board, National Research Council: Washington, D.C., National Academy of Science Press, 22 p.

Coastal Resources Management Council, 1983, The State of Rhode Island coastal resources management program, as amended: University of Rhode Island Publications Office, Kingston, Rhode Island, 144 p. plus addendum.

Dacey, M.F., 1989, Barrier/lagoon stratigraphy and hydrography [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 152 p.

Dein, M.G., 1981, A quantitative, photogrammetric analysis of Narragansett Bay, Rhode Island shoreline changes, 1938-1975 [M.S. thesis]: Kingston, Rhode Island, Unviersity of Rhode Island, 134 p.

Dean, R.G., 1985, Coastal armoring: Effects, principles and mitigation: Proceedings: 20th Conference of Coastal Engineering, Taiwan: American Society of Civil Engineering, p. 1843-1857.

DeKay, L.E., 1981, Morphodynamics of an undernourished barrier beach, East Beach, Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 123 p.

Dillon, W.P., 1970, Submergence effects on a Rhode Island barrier and lagoon and inferences on migration of barriers: Journal of Geology, v. 78, p. 94-106.

Emery, K.O., 1961, A simple method of measuring beach profiles: Limnology and Oceanography, v. 6, p. 90-93.

Federal Emergency Management Agency, 1986a, Flood Insurance Study: Town of Charlestown, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1986b, Flood Insurance Study: Town of Kingstown, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1986c, Flood Insurance Study: Town of Narragansett, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1986d, Flood Insurance Study: Town of Westerly, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1981, Ways of estimating wave heights in coastal high hazard areas in the Atlantic and Gulf Coast regions: 89 p.

Fisher, J.J., and Simpson, E.J., 1979, Washover and tidal sedimentation rates as environmental factors in development of a transgressive barrier shoreline, *in* Leatherman, S.P., ed., Barrier Island-Gulf of Mexico to Gulf of St. Lawrence: New York, Academic Press, p. 127-148.

Fisher, J.J., 1980, Shoreline erosion, Rhode Island and North Carolina coasts--tests of Bruun Rule, *in* Schwartz, M.L., and Fisher, J.J., eds., Proceedings of the Per Bruun Symposium, Newport, Rhode Island, November 1979: Bellingham, Washington, Bureau for Faculty Research, Western Washington University, p. 32-54.

Galagan, C.W., 1990, The effect of future sea level rise on the southern shore of Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 66 p.

Godfrey, P.J., and Godfrey, M.M., 1973, Comparison of ecological and geomorphic interactions between altered and unaltered barrier island systems in North Carolina: *in* Coates, D.R. (ed.), Coastal Geomorphology, S.U.N.Y. Binghamton, Publications in Geomorphology, p. 239-258.

Gornitz, V., and Lebedeff, S., 1987, Global sea-level changes during the past century: *in* Nummedal, D., Pilkey, O.H., and Howard, J.D., eds., Sea-level fluctuation and coastal evolution: SEPM Spec. Pub. 41, p. 3-16.

Graves, S.M., 1991, Morphotomology of Rhode Island barrier shores: A method of distinguishing beach from dune/barrier component histories within a 29 year record of shore zone profile data, with special reference to the role of the beach as a buffer and modulator of erosional coastline retreat: [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, Graduate School of Oceanography, 126 p.

Hansen, J.E., Lacis, A.A., Rind, D.H., and Russell, G.L., 1984, Climate sensitivity to increasing greenhouse gases, *in* Barth, M.C., and Titus, J.G., eds., Greenhouse effect and sea level rise: Van Nostrand Reinhold Co. Inc., New York, NY, p. 57-77.

Hayes, M.O., 1979, Barrier island morphology as a function of tidal and wave regime: *in* Leatherman, S.P., ed., Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico: Academic Press, New York, N.Y., p. 1-27.

Hoffman, J., Keyes, D., and Titus, J., 1983 Projecting future sea level rise: Methodology, estimates to the year 2100, and research needs: 2nd rev. ed. U.S. GPO No. 055-000-00236-3, Washington, D.C., Government Printing Office, 121 p.

Hoffman, J.S., 1984, Estimates of future sea level rise, *in* Barth, M.C., and Titus, J.G., eds., Greenhouse effect and sea level rise - A challenge for this generation: Van Nostrand Reinhold Co., p. 79-103.

Houghton, J.T., Jenkins, G.J., and Ephraums, J.J., 1990, Climate change: The IPCC assessment: Cambridge University Press, Cambridge, p. 365.

Kelley, J.T., Belknap, D.F., Jacobson, G.L., and Jacobson, H.A., 1988, The origin and evolution of salt marshes along the glaciated coastline of Maine, U.S.A.: Journal of Coastal Research, v. 4, p. 649-665.

Kerr, R.A., 1989, Bringing down the sea-level rise: Science, v. 246, p. 1563.

Kraft, J.C., Chrzastowski, M.J., Belknap, D.F., Toscano, M.A., and Fletcher, C.H. III, 1987, The transgressive barrier-lagoon coast of Delaware: morphostratigraphy, sedimentary sequences and responses to relative rise in sea level: *in* Nummedal, D., Pilkey, O.H., and Howard, J.D., eds., Sea-level fluctuation and coastal evolution: Society of Economic Paleontologists and Mineralogists Special Publication No. 41, p. 129-143.

Kraus, N.C., 1988, The effects of seawalls on the beach: An extended literature review: Journal of Coastal Research, Special Issue No. 4, p. 1-28.

Leatherman, S.P., 1979, Migration of Assateague Island, Maryland by inlet and overwash processes: Geology, v. 7, p. 104-107.

Leatherman, S.P., 1983, Geomorphic effects of projected sea level rise: A case study of Galveston Bay, Texas: Proceedings of Coastal Zone 83, American Society of Civil Engineering, p. 2890-2901.

Leatherman, S.P., 1984, Coastal geomorphic responses to sea level rise, *in* Barth, M.C., and Titus, J.G., eds., Greenhouse effect and sea level rise - A challenge for this generation, Van Nostrand Reinhold Co., p. 151-178.

Lyles, S.D., Hickman, L.E., and DeBaugh, H.A., 1987, Sea level variations for the United States 1855-1986: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, 182 p.

McGinn, S.R., 1982, Facies distribution in a microtidal barrier-lagoon system Ninigret Pond, Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 138 p.

McMaster, R.L., (compiler) and others, 1961-present, Transit surveying of selected Block Island Sound beaches in Washington county Rhode Island [unpub. Annual reports], Coastal Resources Center, University of Rhode Island: Kingston, Rhode Island.

Meier, M.F., 1989, Reduced rise in sea level: Nature, v. 343, p. 115-116.

National Academy of Sciences, 1977, Methodology for calculating wave action effects associated with storm surges: Washington, D.C., 29 p.

National Academy of Sciences, 1990, Managing Coastal Erosion: National Academy Press, Washington, D.C., 182 p.

National Oceanic and Atmospheric Administration, 1988, Tide Tables 1989, High and Low Water Predictions, East Coast of North and South America Including Greenland: Dept. of Commerce, Washington, D.C., 289 p.

Nichols, R.L., and Marston, A.F., 1939, Shoreline changes in Rhode Island produced by hurricane of September 21, 1938: Geological Society of America Bulletin, v. 50, p. 1357-1370.

Nummedal, D., and Fischer, I.A., 1978, Process-response models for depositional shorelines: the German and the Georgia Bights: Proceedings of 16th Conference of Coastal Engineers, American Society of Civil Engineers, p. 1215-1231.

Peltier, W.R., and Tushingham, A.M., 1989, Global sea level rise and the greenhouse effect: Might they be connected?: Science, v. 244, p. 806-810.

Penland, S., Suter, J.R., and Boyd, R., 1985, Barrier island area along abandoned Mississippi River deltas: Marine Geology, v. 63, p. 197-233.

Pilkey, O.H., and Wright, H.L., 1988, Seawalls versus beaches: Journal of Coastal Research, Special Issue No. 4, p. 41-66.

Pilkey, O.H., Morton, R.A., Kelley, J.T., and Penland, S., 1989, Coastal land loss: Washington, D.C., American Geophysical Union, 73 p.

Pirazzoli, P.A., 1989, Present and near-future sea-level changes: Global and Planet Change, v. 75, p. 241-258.

Redfield, A.C., and Rubin, M., 1962, The age of salt marsh peat and its relation to recent changes in sea level at Barnstable, Massachusetts: Proc. National Academy of Sciences, p. 1728-1735.

Rosenberg, M.J., 1985, Temporal variability of beach profiles, Charlestown beach, Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 358 p.

Schafer, J.P., 1961, Surficial geology of the Narragansett Pier Quadrangle, Rhode Island: Washington, D.C., U.S. Geological Survey.

Scott, D.B., Boyd, R., and Medioli, F.S., 1987, Relative sea-level changes in Atlantic Canada: Observed level and sedimentological changes versus tehoretical models: Society of Economic Paleontologists and Mineralogists Special Publication No. 41, p. 87-96.

Smagorinsky, J., 1982, Carbon dioxite: A second assessment: Washington, D.C., National Academy Press.

U.S. Army Corps of Engineers, New England Division, 1988, Tidal flood profile no. 5, New England coastline: Waltham, MA.

Williams, S.J., and Meisburger, E.P., 1987, Sand sources for the transgressive barrier coast of Long Island, N.Y.: Evidence for landward transport of shelf sediments: Proceedings of American Society of Civil Engineers Specialty Conference on Coastal Sediments '87, New Orleans, Louisiana.

APPENDIX

AutoLISP Programs

```
;
;                        PROFILE.LSP
;                            by
;                       Denis Newcomer


;__________________________________________________________

;   This program reads x-y coords from a space delimited
;   ascii file, feeds them to the LINE command and draws
;   lines between the coord. points.
;__________________________________________________________


(Defun C:F();                          ;defines the function LINES


;  This set of commands allows user to enter name of profile
;  into a layer


(setq name (getstring "Enter layer name: "))
(command "LAYER" "M" name "")


;*********************************************************
;  The next set of statements reads in the name of an ascii
;  file and allows the user to insert a vertical exag.
;  based on an xscale and yscale factor


(Setq file  (GetString "Enter name of ascii file to be read: "))
(Setq fname (open file "r"))      ; opens ascii file for reading
(Setq xscale (getreal "Enter # of meters per horiz. inch:"))
(Setq yscale (getreal "Enter # of meters per vert. inch: "))


;*********************************************************
;  Reads individual lines of ascii code and separates the
;  x-coordinate and y-coordinate.  The x-coordinate begins
;  at column 1 and continues for 12 more cols.  The y-coord
;  is read beginning with the 15 col. and continues for 8
;  more columns.  Spaces are stripped from line and the
;  x- and y-coordinates are saved as pt1 and pt2.


  (Setq record (Read-Line fname)) ; reads first line of file
  (While (/= record "EOF")        ; begin loop to extract x-y values
    (Setq pt1 ())                 ; defines list for first x-y pair
    (Setq xcoord (SubStr record 1 12)) ; extracts xcoord from text line
    (Setq ycoord (SubStr record 15 8)) ; extracts ycoord from text line

    (Setq xval (Read xcoord))     ; strips spaces, etc. from string
```

```
    (Setq yval (Read ycoord))     ; strips spaces, etc. from string

    (Setq pt1 (Cons (/ yval yscale) pt1)) ; puts y value in
                                          ; list pt1 & scales
    (Setq pt1 (Cons (/ xval xscale) pt1)) ; puts x value in
                                          ; list pt2 & scales

    (Setq record (Read-Line fname)) ; reads next line from ascii file
    (if (/= record "EOF")
      (progn
        (Setq pt2 ())           ; defines list for second x-y pair
        (Setq xcoord (SubStr record 1 12))
        (Setq ycoord (SubStr record 15 8))

        (Setq xval (Read xcoord))
        (Setq yval (Read ycoord))

        (Setq pt2 (Cons (/ yval yscale) pt2))
        (Setq pt2 (Cons (/ xval xscale) pt2))

;************************************************************
;  In this last section, the line is drawn from pt1 to pt2
;  and then returns to the previous section to read the next
;  input line from the ascii file.  This program ends when
;  "EOF" is encountered at the x-coordinate position.

        (command "LINE" pt1 pt2)    ; draws line from pt1 to pt2
        (command "")                ; current layer

      )
    )
  )                                ; end loop

(close fname)                       ; close text file
)
```

```
;                              BOX.LSP
;                                 by
;                           Denis Newcomer

;_____________________________________________________________

;  This program draws a box, ticks, x- and y-axis numbers
;  and legend, and a title.  It prompts the user for the
;  lower left and upper right corners of the box, x- and y-
;  axis legends, and a horizontal and vertical scale factor.
;_____________________________________________________________

;                            BOX ROUTINE
;  This section draws a box based on coordinates given by
;  the user for the lower left and upper right corners of
;  the desired box.  In addition, the user is asked to
;  provide a horizontal and vertical scale factor.


(setq box "box")                     ;Name LAYER "box"
(command "LAYER" "M" box "")


(setq ll (getpoint "\nPick LL corner: ")
      ura (getcorner "\nPick UR corner: " ll)
      xscale 10 ;(getreal "\What is the horiz. scale: ")
      yscale 2  ; (getreal "\What is the vert. scale: ")
      x1a (car ll)
      y1a (cadr ll)
      x2a (car ura)
      y2a (cadr ura)
      x1 (/ x1a xscale)
      y1 (/ y1a yscale)
      x2 (/ x2a xscale)
      y2 (/ y2a yscale)
      ll (list x1 y1)
      ul (list x1 y2)
      lr (list x2 y1)
        ur (list x2 y2)
)

(command "PLINE" ll "W" 0 "" lr ur "W" 0 "" ul "C") ;draws box


;************************************************************

;                    DRAWS TICKS ON X-AXIS
(setq xpt1 0)
(setq ixp 0)
(setq count 0)
(setq xvalue (/ (- x2a x1a) xscale))  ; # of ticks
(setq ct (/ x1a xscale))
```

```
; determines proper hts of numbers and axis legends
(setq xlength (- x2a x1a))
(setq htratio (/ 2862.63 xlength))
(setq ht (/ 0.4 htratio))

(while (<= count (fix xvalue))
  (setq xp (list (+ count (- ct ixp)) y1)) ;calcs x position
      (if (> count 0) (setq ct (fix ct)))

     ; if lower left corner of box is less than 0 and a
     ; a fraction of the x scaling factor, this routine
     ; is used.
      (if (/= ct (fix ct))
        (progn
         (setq integ (fix ct))
         (setq ixp (- ct integ))
         (setq xp (list (- ct ixp) yl)
      ))

     ; y position is calculated and paired with calculated
     ; x position.
      (setq ct (/ x1a xscale))
      (setq yp (+ y1 0.15))
     (setq xy1 (list (+ count (- ct ixp)) yp))

     ; Spacing is adjusted between box, legends and nos.
     ; Centerpoint of tick is determined.
     (setq spacing (* (/ ht 0.2) 0.3))
      (setq cpt (list (+ count (- ct ixp)) (- y1 spacing)))

     ; Value of tick is determined
      (setq xpta (+ xpt1 (* count xscale)))
      (if (= count 0)
       (progn
       (setq xpt1 (* (fix ct) xscale))
       (setq xpta xpt1)
      ))

      (setq xpt (fix xpta))          ;integer value of tick #

     ; Numbers axis in increments of 100
      (setq n (/ (fix xpta) 100))
      (setq d (/ (float xpta) 100))
      (if (= n d)
       (progn

       ; Y position is recalculated and then paired with x
       ; position.
        (setq yp (+ y1 0.30))
        (setq xy1 (list (+ count (- ct ixp)) yp))
        (setq gogo 1)
      ))
```

```
       ;  Draws and numbers ticks
        (setq tick "ticks")
        (command "LAYER" "M" tick "")
       (command "LINE" xp xy1 "")

        (if (= gogo 1)
         (progn
          (setq tick "x_axis_nos")
          (command "LAYER" "M" tick "")
          (command "TEXT" "C" cpt ht 0 xpt)
          (setq gogo 0)
        ))

      (setq count (1+ count))          ;increases counter by 1
); ends loop

;***********************************************************
;                    DRAWS TICKS ON Y-AXIS
(setq count 0)
(setq yvalue (/ (- y2a y1a) yscale))
(setq ct (/ y1a yscale))
(setq iyp 0)

(while (<= count yvalue)

      (setq yp (list x1 (+ count (- ct iyp))))
      (if (> count 0) (setq ct (fix ct)))
      (if (/= ct (fix ct))
       (progn
        (setq integ (fix ct))
        (setq iyp (- ct integ))
        (setq yp (list x1 (- ct iyp)))
      ))

      (setq ct (/ y1a yscale))
      (setq xp (+ x1 0.15))
      (setq d1 (list xp (+ count (- ct iyp))))

      (setq rpt (list (- x1 spacing) (+ count (- ct (+ iyp 0.1)))))

      (setq ypta (* (+ (fix y1) count) 2))
      (setq ypt (fix ypta))

      (setq tick "ticks")
      (command "LAYER" "M" tick "")
      (command "LINE" yp d1 "")
      (setq tick "y_axis_nos")
      (command "LAYER" "M" tick "")
      (command "TEXT" "R" rpt ht 0 ypt)

      (setq count (1+ count))
)
```

```
;************************************************************
;                    LABEL X- & Y-AXIS

;  Mid-point of x axis is determined and then the legend is
;  added.
(setq label "x_axis_text")
(command "LAYER" "M" label "")
(setq xmid (- x2 (/ (- x2 x1) 2)))
(setq lspacing (* (/ ht 0.1913) -0.6))
(setq ymid (+ y1 lspacing))
(setq mid (list xmid ymid))
(setq xname "distance from 1990 MSL (m)")
                              ;(getstring T "X-axis label is :"))

(Command "TEXT" "C" mid ht 0 xname)       ;print out

;  Same as above except for y-axis.
(setq label "y_axis_text")
(command "LAYER" "M" label "")
(setq ymid (- y2 (/ (- y2 y1) 2)))
(setq lspacing (* lspacing -1))
(setq midd (list (- x1 lspacing) ymid))
(setq yname "elevation above 1990 MSL (m)");NGVD (m)")
                ;(getstring T "Y-axis label is :"))

(Command "TEXT" "C" midd ht 90 yname)       ;print out
```

BIBLIOGRAPHY

Autodesk Inc., 1990, AutoCAD Release 11 software and Reference Manual: Autodesk Inc., 640 p.

Barnett, T.P., 1983, Recent changes in sea level and their possible causes: Climate Change, v. 5, p. 15-38.

Barron, E.J., Thompson, S.L., and Schneider, S.H., 1981, An ice-free Cretaceous results from climate model simulators: Science, v. 212, p. 501-508.

Boothroyd, J.C., Cable, M.S., O'Brien, J.H., McCreery, C.J., and Russell, F.D., 1978, Beach erosion and recovery: Charlestown, Rhode Island: *in* Jones, J.R., ed., The Blizzard of 1978: Its Effects on the Coastal Environments of Southeastern New England, Boston State College, p. 81-90.

Boothroyd, J.C., Friedrich, N.E., McGinn, S.R., Schmidt, C.A., Rosenberg, M.J., Peters, C.R., O'Brien, J.H., and Dunne, L.A., 1981, The geology of selected microtidal lagoons, Rhode Island, v. I & II: Technical Report No. 2-SRG, Department of Geology, University of Rhode Island, Kingston, Rhode Island, 576 p.

Boothroyd, J.C., Friedrich, N.E., and McGinn, S.R., 1985, Geology of selected microtidal lagoons: Rhode Island, *in* Oertel, G.F., and Leatherman, S.P., eds., Barrier Islands: Marine Geology, v. 63, p. 35-76.

Boothroyd, J.C., 1985, Geologic processes pose problems for the Rhode Island shore: Maritimes, v. 29, no. 2, p. 1-3.

Boothroyd, J.C., Gibeaut, J.C., Dacey, M.F., 1986, Geological aspects of shoreline management: a summary for southern Rhode Island, I. Regional depositional systems and a long-term profiling network, Vol. 1: Technical Report No. 6-SRG, University of Rhode Island Sea Grant Final Report, Contract No. NA85AA-D-SG094, Project No. R/CS-1, 104 p.

Boothroyd, J.C., Galagan, C.W., and Graves, S.M., 1988a, Advance and retreat of the southern Rhode Island shoreline, 1939-1985: including 1985 berm volume: Technical Report No. 7-SRG, Sea Grant College Program, University of Rhode Island, Contract No. NA85AA-D-SG094, Project No. R/CR-871, 92 p.

Boothroyd, J.C., Graves, S.M., and Galagan, C.W., 1988b, The Rhode Island long-term beach profile network: 1986-1988 data: Technical Report No. 7-SRG, Sea Grant College Program, University of Rhode Island, Contract No. NA85AA-D-SG094, Project No. R/CR-871, 119 p.

Borland International Inc.,2222 1991, Quattro Pro Release 3.0 software and Reference Manual: Borland International Inc., 807 p.

Braatz, B.V., and Aubrey, D.G., 1987, Recent relative sea-level change in eastern North America, *in* Nummedal, D., Pilkey, O.H., and Howard, J.D., eds., Sea-level fluctuation and coastal evolution: Society of Economic Paleontologists and Mineralogists Special Publication No. 41, p. 29-46.

Bruun, P., 1954, Coastal erosion and development of beach profiles, Beach Erosion Board Technical Memorandum No. 44: Washington, D.C., U.S. Army Corps of Engineers.

Bruun, P., 1962, Sea-level rise as a cause of shore erosion: Proceedings of the American Society of Civil Engineers: Journal of the Waterways and Harbors Division, v. 88, no. WWI, p. 117-130.

Charney, J., chairman, Climate Research Board, 1979, Carbon dioxide and climate: A scientific assessment/Report of an ad hoc group on carbon dioxide and climate, Woods Hole, MA, July 23-29, 1979 to the Climate Research Board, National Research Council: Washington, D.C., National Academy of Science Press, 22 p.

Coastal Resources Management Council, 1983, The State of Rhode Island coastal resources management program, as amended: University of Rhode Island Publications Office, Kingston, Rhode Island, 144 p. plus addendum.

Dacey, M.F., 1989, Barrier/lagoon stratigraphy and hydrography [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 152 p.

Dein, M.G., 1981, A quantitative, photogrammetric analysis of Narragansett Bay, Rhode Island shoreline changes, 1938-1975 [M.S. thesis]: Kingston, Rhode Island, Unviersity of Rhode Island, 134 p.

Dean, R.G., 1985, Coastal armoring: Effects, principles and mitigation: Proceedings: 20th Conference of Coastal Engineering, Taiwan: American Society of Civil Engineering, p. 1843-1857.

DeKay, L.E., 1981, Morphodynamics of an undernourished barrier beach, East Beach, Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 123 p.

Dillon, W.P., 1970, Submergence effects on a Rhode Island barrier and lagoon and inferences on migration of barriers: Journal of Geology, v. 78, p. 94-106.

Emery, K.O., 1961, A simple method of measuring beach profiles: Limnology and Oceanography, v. 6, p. 90-93.

Federal Emergency Management Agency, 1986a, Flood Insurance Study: Town of Charlestown, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1986b, Flood Insurance Study: Town of Kingstown, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1986c, Flood Insurance Study: Town of Narragansett, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1986d, Flood Insurance Study: Town of Westerly, Rhode Island, Washington County, 24 p.

Federal Emergency Management Agency, 1981, Ways of estimating wave heights in coastal high hazard areas in the Atlantic and Gulf Coast regions: 89 p.

Fisher, J.J., and Simpson, E.J., 1979, Washover and tidal sedimentation rates as environmental factors in development of a transgressive barrier shoreline, *in* Leatherman, S.P., ed., Barrier Island-Gulf of Mexico to Gulf of St. Lawrence: New York, Academic Press, p. 127-148.

Fisher, J.J., 1980, Shoreline erosion, Rhode Island and North Carolina coasts--tests of Bruun Rule, *in* Schwartz, M.L., and Fisher, J.J., eds., Proceedings of the Per Bruun Symposium, Newport, Rhode Island, November 1979: Bellingham, Washington, Bureau for Faculty Research, Western Washington University, p. 32-54.

Galagan, C.W., 1990, The effect of future sea level rise on the southern shore of Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 66 p.

Godfrey, P.J., and Godfrey, M.M., 1973, Comparison of ecological and geomorphic interactions between altered and unaltered barrier island systems in North Carolina: *in* Coates, D.R. (ed.), Coastal Geomorphology, S.U.N.Y. Binghamton, Publications in Geomorphology, p. 239-258.

Gornitz, V., and Lebedeff, S., 1987, Global sea-level changes during the past century: *in* Nummedal, D., Pilkey, O.H., and Howard, J.D., eds., Sea-level fluctuation and coastal evolution: Society of Economic Paleontologists and Mineralogists Special Publication 41, p. 3-16.

Graves, S.M., 1991, Morphotomology of Rhode Island barrier shores: A method of distinguishing beach from dune/barrier component histories within a 29 year record of shore zone profile data, with special reference to the role of the beach as a buffer and modulator of erosional coastline retreat: [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, Graduate School of Oceanography, 126 p.

Hansen, J.E., Lacis, A.A., Rind, D.H., and Russell, G.L., 1984, Climate sensitivity to increasing greenhouse gases, *in* Barth, M.C., and Titus, J.G., eds., Greenhouse effect and sea level rise: Van Nostrand Reinhold Co. Inc., New York, NY, p. 57-77.

Hayes, M.O., 1979, Barrier island morphology as a function of tidal and wave regime: *in* Leatherman, S.P., ed., Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico: Academic Press, New York, N.Y., p. 1-27.

Hoffman, J., Keyes, D., and Titus, J., 1983 Projecting future sea level rise: Methodology, estimates to the year 2100, and research needs: 2nd rev. ed. U.S. GPO No. 055-000-00236-3, Washington, D.C., Government Printing Office, 121 p.

Hoffman, J.S., 1984, Estimates of future sea level rise, *in* Barth, M.C., and Titus, J.G., eds., Greenhouse effect and sea level rise - A challenge for this generation: Van Nostrand Reinhold Co., p. 79-103.

Houghton, J.T., Jenkins, G.J., and Ephraums, J.J., 1990, Climate change: The IPCC assessment: Cambridge University Press, Cambridge, p. 365.

Kelley, J.T., Belknap, D.F., Jacobson, G.L., and Jacobson, H.A., 1988, The origin and evolution of salt marshes along the glaciated coastline of Maine, U.S.A.: Journal of Coastal Research, v. 4, p. 649-665.

Kerr, R.A., 1989, Bringing down the sea-level rise: Science, v. 246, p. 1563.

Kraft, J.C., Chrzastowski, M.J., Belknap, D.F., Toscano, M.A., and Fletcher, C.H. III, 1987, The transgressive barrier-lagoon coast of Delaware: morphostratigraphy, sedimentary sequences and responses to relative rise in sea level: *in* Nummedal, D., Pilkey, O.H., and Howard, J.D., eds., Sea-level fluctuation and coastal evolution: Society of Economic Paleontologists and Mineralogists Special Publication No. 41, p. 129-143.

Kraus, N.C., 1988, The effects of seawalls on the beach: An extended literature review: Journal of Coastal Research, Special Issue No. 4, p. 1-28.

Leatherman, S.P., 1979, Migration of Assateague Island, Maryland by inlet and overwash processes: Geology, v. 7, p. 104-107.

Leatherman, S.P., 1983, Geomorphic effects of projected sea level rise: A case study of Galveston Bay, Texas: Proceedings of Coastal Zone 83, American Society of Civil Engineering, p. 2890-2901.

Leatherman, S.P., 1984, Coastal geomorphic responses to sea level rise, *in* Barth, M.C., and Titus, J.G., eds., Greenhouse effect and sea level rise - A challenge for this generation, Van Nostrand Reinhold Co., p. 151-178.

Lyles, S.D., Hickman, L.E., and DeBaugh, H.A., 1987, Sea level variations for the United States 1855-1986: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, 182 p.

McGinn, S.R., 1982, Facies distribution in a microtidal barrier-lagoon system Ninigret Pond, Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 138 p.

McMaster, R.L., (compiler) and others, 1961-present, Transit surveying of selected Block Island Sound beaches in Washington county Rhode Island [unpub. Annual reports], Coastal Resources Center, University of Rhode Island: Kingston, Rhode Island.

Meier, M.F., 1989, Reduced rise in sea level: Nature, v. 343, p. 115-116.

National Academy of Sciences, 1977, Methodology for calculating wave action effects associated with storm surges: Washington, D.C., 29 p.

National Academy of Sciences, 1990, Managing Coastal Erosion: National Academy Press, Washington, D.C., 182 p.

National Oceanic and Atmospheric Administration, 1988, Tide Tables 1989, High and Low Water Predictions, East Coast of North and South America Including Greenland: Dept. of Commerce, Washington, D.C., 289 p.

Nichols, R.L., and Marston, A.F., 1939, Shoreline changes in Rhode Island produced by hurricane of September 21, 1938: Geological Society of America Bulletin, v. 50, p. 1357-1370.

Nummedal, D., and Fischer, I.A., 1978, Process-response models for depositional shorelines: the German and the Georgia Bights: Proceedings of 16th Conference of Coastal Engineers, American Society of Civil Engineers, p. 1215-1231.

Peltier, W.R., and Tushingham, A.M., 1989, Global sea level rise and the greenhouse effect: Might they be connected?: Science, v. 244, p. 806-810.

Penland, S., Suter, J.R., and Boyd, R., 1985, Barrier island area along abandoned Mississippi River deltas: Marine Geology, v. 63, p. 197-233.

Pilkey, O.H., and Wright, H.L., 1988, Seawalls versus beaches: Journal of Coastal Research, Special Issue No. 4, p. 41-66.

Pilkey, O.H., Morton, R.A., Kelley, J.T., and Penland, S., 1989, Coastal land loss: Washington, D.C., American Geophysical Union, 73 p.

Pirazzoli, P.A., 1989, Present and near-future sea-level changes: Global and Planet Change, v. 75, p. 241-258.

Redfield, A.C., and Rubin, M., 1962, The age of salt marsh peat and its relation to recent changes in sea level at Barnstable, Massachusetts: Proc. National Academy of Sciences, p. 1728-1735.

Rosenberg, M.J., 1985, Temporal variability of beach profiles, Charlestown beach, Rhode Island [M.S. thesis]: Kingston, Rhode Island, University of Rhode Island, 358 p.

Schafer, J.P., 1961, Surficial geology of the Narragansett Pier Quadrangle, Rhode Island: Washington, D.C., U.S. Geological Survey.

Scott, D.B., Boyd, R., and Medioli, F.S., 1987, Relative sea-level changes in Atlantic Canada: Observed level and sedimentological changes versus tehoretical models: Society of Economic Paleontologists and Mineralogists Special Publication No. 41, p. 87-96.

Smagorinsky, J., 1982, Carbon dioxite: A second assessment: Washington, D.C., National Academy Press.

U.S. Army Corps of Engineers, New England Division, 1988, Tidal flood profile no. 5, New England coastline: Waltham, MA.

Williams, S.J., and Meisburger, E.P., 1987, Sand sources for the transgressive barrier coast of Long Island, N.Y.: Evidence for landward transport of shelf sediments: Proceedings of American Society of Civil Engineers Specialty Conference on Coastal Sediments '87, New Orleans, Louisiana.